

ECONOMICS AND MANAGEMENT IN PUBLIC HEALTH SERVICE

TWO-COMPONENT ORGANIZATIONAL MODEL FOR CLINICAL AND RADIOLOGICAL SCREENING FOR PULMONARY TUBERCULOSIS IN A SPARSELY POPULATED TERRITORY OF THE SAKHA REPUBLIC (YAKUTIA)

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ABSTRACT

Background. The challenges of organizing tuberculosis detection in sparsely populated areas are primarily associated with poor transportation access and a shortage of medical personnel. Under these conditions, the implementation of modern information technologies in clinical and radiological screening for the disease becomes highly relevant.

Aim. To optimize methods for the detection and diagnosis of pulmonary tuberculosis using information technologies in the sparsely populated territory of the Republic of Sakha (Yakutia).

Methods. A pilot study was conducted in seven medical organizations of the Republic of Sakha (Yakutia) to test a two-component organizational model for clinical and radiological tuberculosis screening utilizing information technologies: a central medical image archive and telemedicine for remote diagnosis, as well as artificial intelligence for double reading of fluorograms. Effectiveness was assessed by monthly monitoring of population coverage with fluorographic examinations, measuring the time spent on double reading of fluorograms, and assessing the time to tuberculosis diagnosis.

Results. The pilot implementation of the two-component organizational model for clinical and radiological tuberculosis screening, employing information technologies and artificial intelligence in medical organizations, led to increased fluorographic examination coverage of the general population and individuals at risk for tuberculosis. This implementation also reduced the time required for double reading of fluorograms and shortened tuberculosis diagnostic timelines, both in the general medical network and at the specialized tuberculosis service level. Considering the specific characteristics of tuberculosis detection organization across different socio-territorial zones of the Far North, a model for clinical and radiological screening of pulmonary tuberculosis was developed. This model comprises two organizational variants tailored for use in the Arctic and industrial zones. The model consists of three stages (radiological, clinical, and specialized) implemented at the level of the central district hospital departments.

Conclusion. The proposed model for tuberculosis screening using information technologies is recommended for implementation in sparsely populated districts of the Far North.

Keywords: pulmonary tuberculosis, mass screening, diagnosis, information technology, telemedicine, artificial intelligence

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ОРГАНИЗАЦИОННАЯ ДВУХКОМПОНЕНТНАЯ МОДЕЛЬ КЛИНИКО-РЕНТГЕНОЛОГИЧЕСКОГО СКРИНИНГА ТУБЕРКУЛЕЗА ЛЕГКИХ В УСЛОВИЯХ МАЛОНАСЕЛЕННОЙ ТЕРРИТОРИИ РЕСПУБЛИКИ САХА (ЯКУТИЯ)

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РЕЗЮМЕ

Обоснование. Сложности организации выявления туберкулеза в малонаселенных территориях связаны в первую очередь с низким уровнем транспортной доступности и дефицитом медицинских кадров. В этих условиях является актуальным внедрение современных информационных технологий (ИТ) в процессы клиничко-рентгенологического скрининга заболевания.

Цель исследования. Оптимизация методов выявления и диагностики туберкулеза легких с использованием ИТ в условиях малонаселенной территории Республики Саха (Якутия).

Методы. В 7 пилотных медицинских организациях Республики Саха (Якутия) проведена апробация Организационной двухкомпонентной модели клиничко-рентгенологического скрининга туберкулеза с применением ИТ: центрального архива медицинских изображений и телемедицины для дистанционной постановки диагноза, а также искусственного интеллекта для двойного чтения флюорограмм. Оценка эффективности проводилась путем ежемесячного контроля охвата населения флюорографическим осмотром, учета временных затрат на двойное чтение флюорограмм и сроков установления диагноза туберкулеза.

Результаты. Апробация в пилотных медицинских организациях Организационной двухкомпонентной модели клиничко-рентгенологического скрининга туберкулеза с применением ИТ и искусственного интеллекта привело к повышению охвата населения и лиц из групп риска по туберкулезу флюорографическими осмотрами, а также к сокращению временных затрат на двойное чтение флюорограмм и сроков диагностики туберкулеза на уровне общей лечебной сети и противотуберкулезной службы. С учетом наличия особенностей в организации выявления туберкулеза в различных социально-территориальных зонах региона Крайнего Севера разработана модель клиничко-рентгенологического скрининга туберкулеза легких, состоящая из двух организационных вариантов для использования в условиях Арктической и Промышленной зон. Модель состоит из трех этапов: рентгенологического, клиничко-специализированного, осуществляемых на уровне подразделений центральной районной больницы.

Заключение. Предложенная модель скринингового обследования на туберкулез с использованием ИТ рекомендована для применения в малонаселенных районах Крайнего Севера.

Ключевые слова: туберкулез легких, скрининг, выявление, диагностика, информационные технологии, телемедицина, искусственный интеллект

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BACKGROUND

The organization of early tuberculosis detection among the population is a crucial component of tuberculosis control efforts, as delayed or late diagnosis negatively affects the epidemiological situation [1, 2]. This is due to the fact that late detection of pulmonary tuberculosis results in prolonged massive bacterial shedding, creating a significant epidemiological risk for the surrounding population, while the morphological changes that develop are often irreversible or only partially reversible, leading to low treatment efficacy [3].

According to current regulatory documents, fluorography (FLG) is the screening method of choice for mass radiographic examination aimed at early detection of pulmonary tuberculosis among the adult population in the Russian Federation. When pulmonary tuberculosis is suspected following FLG screening at a primary healthcare facility (PHC), a diagnostic workup is performed, including medical history collection, physical examination, complete blood count, three-fold microscopic examination of biological material (sputum) for acid-fast bacilli (AFB), and chest X-ray. The patient is then referred to a tuberculosis facility, where additional diagnostic methods are employed: two-fold sputum microscopy for AFB, culture and molecular genetic testing for etiological diagnosis and drug susceptibility testing (DST), and immunodiagnosics.

The diagnosis of tuberculosis is confirmed by a medical commission of the tuberculosis medical organization (TB dispensary, hospital, center, or clinic), which makes decisions regarding hospitalization, treatment, and follow-up care. TB dispensaries (departments, offices) submit medical documentation and radiological findings to the commission for review. In complex diagnostic cases, an in-person consultation with the patient is arranged.

As is well known, the key challenges of healthcare delivery in the Arctic zone and the Far North, which are sparsely populated territories, include limited transport accessibility and a shortage of medical personnel [4–6]. In this study, we analyzed the standard algorithm for tuberculosis detection and diagnosis in the Republic of Sakha (Yakutia) for 2017–2019 and identified the following issues that negatively impact the effectiveness and timeliness of detection and diagnosis:

- Staffing shortages, including radiologists: 7 out of 13 (53.8 %) Arctic districts lack radiologists, and in 5 out of 34 (14.7 %) districts, their numbers fall below the required levels;
- The shortage of radiologists in the districts creates difficulties in organizing mandatory double reading of fluorograms during screening, resulting in missed pulmonary pathologies;
- Poorly developed transport infrastructure, especially in Arctic districts with seasonal accessibility to remote settlements, leads to prolonged delays in the delivery of diagnostic material for culture and molecular

genetic testing, as well as patient medical documentation, to the main TB facility of the republic, extending the time to diagnosis to one month or more.

Numerous studies have addressed the optimization of pulmonary tuberculosis detection and diagnosis, including through the use of modern information technologies (IT), in various regions of the Russian Federation. However, no studies addressing this issue in the context of sparsely populated territories of the Far North were found in the available literature. Most studies focus on the use of computer programs for recording and monitoring tuberculosis foci [7, 8] and intelligent systems for detecting pulmonary pathology based on medical images [9–11]. The combined use of IT, including telemedicine and artificial intelligence, to improve tuberculosis detection and diagnosis has not been investigated. Issues related to the identification of pathology during screening fluorographic examination, from both clinical and organizational perspectives, remain insufficiently studied.

The above confirms the relevance of developing measures for the implementation of modern information and digital technologies to improve methods for tuberculosis detection and diagnosis in the Far North region with low population density.

AIM

To optimize methods for the detection and diagnosis of pulmonary tuberculosis using information technologies in the sparsely populated territory of the Republic of Sakha (Yakutia).

MATERIALS AND METHODS

This study employed a zoning scheme of the Republic of Sakha (Yakutia) divided into five socio-territorial zones according to the method of M.A. Tyrylgina [12], modified in accordance with Presidential Decree No. 296 of May 2, 2014 “On the Land Territories of the Arctic Zone of the Russian Federation”:

I. Yakutsk City, the capital of the Republic of Sakha (Yakutia).

II. Arctic Zone, comprising 13 polar and subpolar districts with extensive territory accounting for 45 % of the republic’s area. The lowest population density in the region is 0.04 persons/km², which is 8 times lower than the republic average (0.32 persons/km²). The proportion of indigenous small-numbered peoples of the North is 24 % of the population, significantly higher than in other zones. The main economic activities are reindeer herding, hunting, and fishing.

III. Industrial Zone, comprising 5 districts with developed mining industries (diamond, coal, oil, gas). In this zone, the urban population accounts for 92.6 %, and the non-indigenous population accounts for 92.4 %.

IV. Rural (Agricultural) Zone, consisting of 11 districts of Central Yakutia with stall-based animal husbandry and herd horse breeding, as well as risky agriculture. Here, the rural population accounts for 87.7 %, and the indigenous population accounts for 94.8 %.

V. Mixed Zone, comprising 5 scattered districts with stall-based animal husbandry, herd horse breeding, reindeer herding, risky agriculture, and a small share of mining industry. In the mixed zone, the urban population accounts for 49.4 %, rural – 50.6 %, and indigenous – 53.7 %.

All districts of the Republic of Sakha (Yakutia) are included in the list of territories with low population density, except for 5 districts of the Rural (Agricultural) Zone. Indigenous (native) peoples included the Yakuts (Sakha) and the small-numbered peoples of the North (Even, Evenki, Yukaghir, Chukchi, Dolgan). All other population groups were considered non-indigenous [13].

Starting from 2020, the Scientific and Practical Center “Phthisiology” began developing an algorithm for tuberculosis detection and diagnosis among the adult population using information technologies (IT). Monthly monitoring of population coverage with fluorographic (FLG) examinations was introduced. Telemedicine consultations (TMC) were organized between district primary healthcare physicians and TB specialists at TB dispensary departments of central district hospitals (CDHs) and Yakutsk through the “Cloud Polyclinic” application for diagnostic clarification and registration for follow-up. The telemedicine service “Cloud Polyclinic”, launched in the Republic of Sakha (Yakutia) in 2020, is designed for remote patient-specialist interaction and physician-to-physician consultations.

To evaluate the effectiveness of IT implementation in the TB service, two periods were compared: Period 1 (2014–2016) – traditional methods (pre-IT implementation); Period 2 (2020–2023) – widespread IT implementation (“Cloud Polyclinic”, ArchiMed system, TMC, and “Predict” software).

From 2022, work was conducted jointly with the Faculty of Computational Mathematics and Cybernetics of Lomonosov Moscow State University to process the FLG image database using a prototype interactive tool for radiographic image annotation to train diagnostic deep neural networks. The effectiveness of primary and secondary reading of digital fluorograms with a clinical decision support system in radiological screening for pulmonary tuberculosis was compared using expert evaluation, with accuracy, sensitivity, and specificity calculated [14]. As a result, a neural network diagnostic model for tuberculosis, the “Predict” software, was developed and included in the algorithm.

In 2022, the Ministry of Health of the Republic of Sakha (Yakutia) approved a pilot project for the implementation and testing of new information technologies to improve the effectiveness of tuberculosis detection and diagnosis among the republic’s population.

Seven pilot healthcare facilities were selected from each socio-territorial zone for algorithm implementation:

- Yakutsk City (Yakutsk City Hospital No. 2, Yakutsk City Hospital No. 3);
- Arctic Zone (Bulunskaya Central District Hospital);
- Industrial Zone (Aldanskaya Central District Hospital);
- Rural (Agricultural) Zone (Verkhnevilyuyanskaya Central District Hospital; Megino-Kangalasskaya Central District Hospital);
- Mixed Zone (Khangalasskaya Central District Hospital).

As shown in Figure 1, within the pilot healthcare facilities, at the first (radiological) stage of the algorithm for pulmonary tuberculosis detection and diagnosis during FLG screening of the adult population, the radiologist at the FLG unit uploads digital fluorograms to the Central Archive of Medical Images (ArchiMed system). For primary reading of fluorograms, the “Predict” software is used to prioritize images for radiologist review, highlighting radiological syndromes as a clinical decision support system. This is followed by secondary reading by a radiologist. The list of cases that have been identified as having pathological changes in their chest organs (referred to as “FLG-positive”) is transmitted by the authorized facility’s official to the primary care physicians, with the results of any further examinations being returned to the FLG unit. An electronic record of the subsequent follow-up for these cases is maintained within the FLG department.

At the second (clinical) stage, the district primary care physician at the healthcare facility performs a follow-up examination of “FLG-positive” individuals. When symptoms suggestive of tuberculosis are identified, the patient is referred to a phthiatrician (TB specialist) at the TB Dispensary Department of the Central District Hospital or the Yakutsk City TB Dispensary Department.

At the third (specialized) stage, following completion of the patient’s diagnostic workup, the phthiatrician conducts a telemedicine consultation (TMC) with the Scientific and Practical Center for Phthisiology via the Cloud Polyclinic platform to confirm the diagnosis of tuberculosis and to enroll the patient in dispensary follow-up. The results of the follow-up examination are transmitted back to the district primary care physician.

The effectiveness of algorithm implementation was assessed through monthly monitoring of the following parameters: population coverage with fluorographic (FLG) screening; proportion of “FLG-positive” individuals who completed follow-up examination; coverage of preventive screenings among tuberculosis risk groups; time intervals to tuberculosis diagnosis, measured from both the date of initial presentation to the primary healthcare facility and the date of referral to the phthiatrician.

For statistical analysis, descriptive statistics methods were employed, including calculation of means

Algorithm for detection and diagnosis of respiratory tuberculosis during FLG screening of the adult population

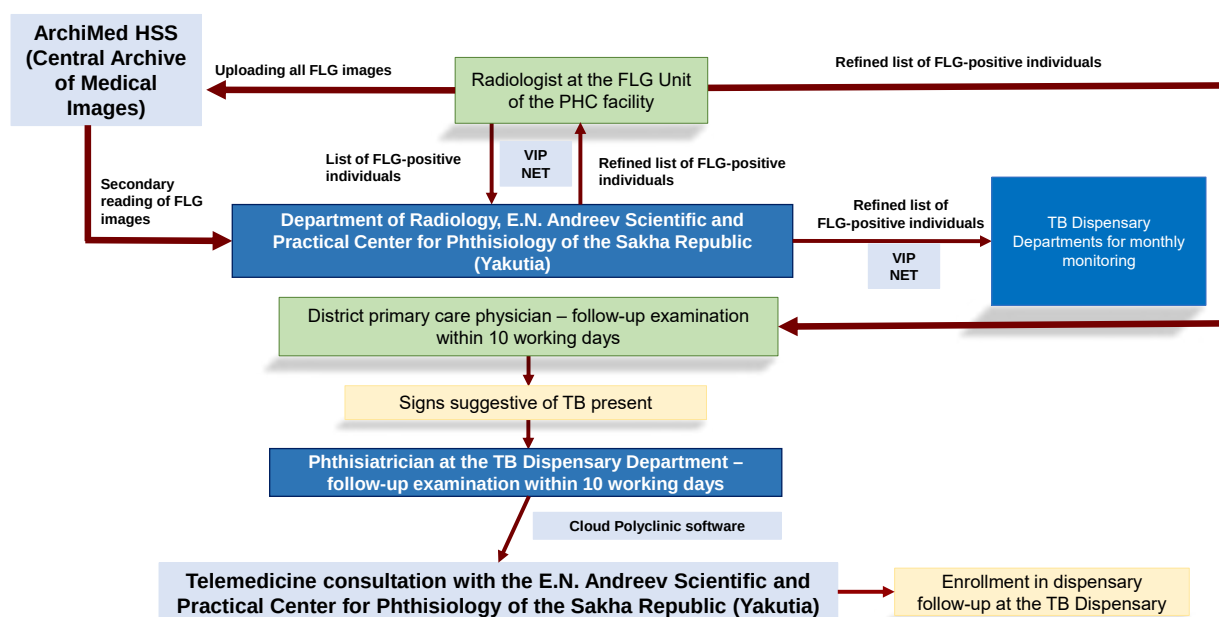


FIG. 1.

Algorithm for the detection and diagnosis of pulmonary tuberculosis during mass X-ray screening of the adult population in pilot health-care facilities

(M), standard errors (m), and proportions (%), allowing assessment of preventive screening coverage, diagnostic timeframes, and other indicators. To compare algorithm effectiveness before and after information technology implementation, Student's *t*-test was used, confirming the statistical significance of differences ($p < 0.05$). Diagnostic accuracy of the methodology was evaluated through calculation of sensitivity, specificity, and overall accuracy, as well as by expert assessment during validation of primary and secondary fluorogram readings.

RESULTS

To evaluate the effectiveness of the algorithm for tuberculosis detection and diagnosis among the adult population using information technologies, the Scientific and Practical Center for Phthisiology conducted monthly monitoring of the following parameters: fluorography (FLG) screening coverage of the catchment population; timeframes and proportion of FLG-positive individuals who completed follow-up examination; and monthly monitoring of preventive screening coverage for tuberculosis among risk groups in pilot healthcare facilities, compared with other healthcare facilities in the republic.

In healthcare facilities not included in the pilot project, the coverage of preventive screening for tuberculosis by FLG during the period 2017–2019 ranged

from 85.0 % to 87.9 %, averaging 2.0 % higher than in the pilot facilities. Following the launch of the project, the coverage rate in pilot facilities increased, reaching 82.6–88.7 % over the period 2020–2023, which exceeded the corresponding rate in the remaining healthcare facilities by an average of 3.2 %.

Analysis of preventive screening coverage among tuberculosis risk groups in pilot versus non-pilot healthcare facilities in 2022–2023 demonstrated that coverage of both medical and social risk groups was higher in pilot facilities. In 2022, preventive screening coverage of medical risk groups in pilot Central District Hospitals (CDHs) was 92.3 %, increasing to 95.2 % in 2023, thereby reaching the target indicator of 95 %. In the remaining CDHs, the corresponding rates were 88.0 % and 88.3 %, respectively. In pilot healthcare facilities of Yakutsk City, coverage decreased from 99.8 % in 2022 to 95.9 % in 2023, remaining above the target threshold. In non-pilot facilities, the indicator remained below the required level (90.8 % in 2022 and 84.0 % in 2023).

Coverage of preventive screening among social risk groups in pilot CDHs increased from 80.9 % in 2022 to 86.9 % in 2023, though it did not reach the target indicator. In non-pilot CDHs, the indicator was insufficient, although it increased from 79.9 % to 84.3 %. In pilot healthcare facilities of Yakutsk City, screening coverage for social risk groups during the study period ranged from 96.6 % to 100 %, compared with 90.6–97.6 % in non-pilot facilities.

Analysis of the proportion of FLG-positive individuals who did not complete follow-up examination in pilot versus non-pilot healthcare facilities in 2022 and 2023 revealed that, in facilities not currently included in the project, the proportion of individuals with FLG changes who were not fully examined decreased in both CDHs (1.4–1.6 % vs. 2.1–2.2 %) and Yakutsk City healthcare facilities (3.1–6.8 % vs. 12.8–14.6 %).

The implementation of information technologies in pilot healthcare facilities enabled minimization of missed pathology during FLG screening of the population for tuberculosis and reduced the timeframes for diagnosis and enrollment of patients in dispensary follow-up. As shown in Table 1, following IT implementation in pilot CDHs, the mean time interval from initial presentation at primary healthcare facilities to referral to a phthisiatrician was reduced by 22.7 days, and the mean time interval from presentation at the CDH TB Dispensary Department to confirmation of tuberculosis diagnosis was reduced by 32.9 days. Both differences were statistically significant ($p = 0.001292$; $p = 0.001925$, respectively).

Thus, the pilot implementation of the developed algorithm for clinical and radiological tuberculosis screening using information technologies in pilot healthcare facilities has led to positive changes in pulmonary tuberculosis detection through the organization of secondary reading of FLG images in the Central Archive of Medical Images by radiologists from the core institution, monthly monitoring of population coverage with FLG screening, preventive screening coverage of medical and social risk groups, and follow-up examination of FLG-positive individuals, as well as a significant reduction in tuberculosis diagnostic timeframes through the transmission of patient medical documentation via the Cloud Polyclinic platform and the conduct of telemedicine consultations for diagnosis confirmation.

To test the “Predict” software in 2023–2024, double reading of digital fluorograms using artificial intelligence (AI) was organized and conducted at primary healthcare facilities. The AI performed

the primary reading of all FLG images, while the radiologist at the primary healthcare facility performed the secondary reading of the same images, taking into account the AI results. During the testing phase, radiologists from the Scientific and Practical Center for Phthisiology performed quality control of the primary and secondary reading reports for 16,427 FLG images included in the study. Based on the results of double reading (AI + radiologist), 468 cases of pathology were suspected, of which clinical and laboratory examination confirmed pulmonary tuberculosis in 135 patients. The diagnosis in all patients was verified through comprehensive examination, including medical history collection, analysis of clinical and laboratory data, chest radiography, and chest computed tomography.

In the current version of the “Predict” software, the system calculates the percentage probability of the presence of pulmonary abnormalities. The highest concordance rate between radiologist and AI readings was observed in the pathology probability range of 0 % to 25 % (93.3–99.7 %). In the 26–60 % range, the concordance rate was 61.9–82.4 %. When the AI-predicted pathology probability exceeded 61 %, radiologists most frequently identified pulmonary abnormalities, including fibrotic changes, inflammatory changes, postoperative changes, sequelae of trauma, as well as congenital pathology of the pulmonary, cardiovascular, and musculoskeletal systems.

ROC analysis of AI performance at the primary FLG screening stage revealed high performance metrics: sensitivity for pathology probability detection was 82 %, and specificity was 81 %.

Following the pilot testing of the algorithm for pulmonary tuberculosis detection and diagnosis in pilot healthcare facilities, in 2024 an Organizational Two-Component Model of Clinical and Radiological Screening for Pulmonary Tuberculosis was developed (hereinafter referred to as the “Model”). The Model is based on the comprehensive application of information and digital technologies to improve pulmonary tuberculosis detection and diagnosis in sparsely

TABLE 1

TIMEFRAME FOR TUBERCULOSIS DIAGNOSIS IN PILOT CENTRAL DISTRICT HOSPITALS BEFORE AND AFTER IMPLEMENTATION OF IT-SOLUTIONS

Follow-up groups	Time from presentation at HCF to referral to TBDD (CDH), days (M+m)	Time from presentation at TBDD (CDH) to diagnosis confirmation, days (M+m)
Pilot CDH before IT implementation, 2014-2016 ($n=55$)	31.3±6.1	45.7±5.0
Pilot CDH after IT implementation, 2020-2023 ($n=31$)	8.6±2.9	12.8±3.9
Student's <i>t</i> -test	3.33	3.2
<i>p</i>	0.001292	0.001925

populated territories. It comprises two Algorithms designed for use in the Arctic and Industrial zones of the Far North. The Organizational Two-Component Model was developed taking into account the existing differences in tuberculosis detection organization across the socio-territorial zones of the region, particularly with the predominantly mobile (outreach) mode of healthcare delivery, including FLG screening of the population in the districts of the Arctic zone.

The developed Algorithms of the Model include three stages: Radiological Stage at the Radiology Department of the Central District Hospital (hereinafter referred to as the First Stage); Clinical Stage at the Outpatient Department of the Central District Hospital (hereinafter referred to as the Second Stage); and Specialized Stage at the level of the phthisiatrician of the TB Dispensary Department of the Central District Hospital (hereinafter referred to as the Third Stage).

In the schematic representation of the Model Algorithms, asterisks with numbers indicate new organizational forms introduced in the work of Central District Hospitals for tuberculosis detection during population FLG screening.

The algorithm for the Arctic Zone (Fig. 2) has several distinctions due to infrastructure characteristics. At the first stage, screening FLG examination of the entire population is conducted by a mobile fluorography team, which provides the FLG Unit of the Central District Hospital with the completed FLG images on a digital storage medium. The radiologist uploads the FLG image database to the ArchiMed Central Archive of Medical

Images and simultaneously to the Predict software for primary reading. Following the receipt of fluorogram reading results from the Predict software, the radiologist performs secondary reading, prioritizing those images identified with a pathology probability of 1 % or higher. After reviewing all fluorographic images, the radiologist prepares a list of FLG-positive individuals and transmits it to the second stage of the Model – the Head of the Polyclinic Department of the Central District Hospital.

At the second stage of the Algorithm, the Head of the Polyclinic Department of the CDH transmits the lists of FLG-positive individuals to a mobile medical team, which specifically travels to populated areas to examine patients with pathology detected during FLG screening. The mobile medical team completes Block 1 of the insert in the outpatient medical record – “Clinical and Radiological Examination of FLG-positive Patient” (hereinafter referred to as the “insert”) and issues a referral for further examination. The insert with completed Block 1 is handed over by the mobile medical team physician to the Head of the Polyclinic Department, who then forwards it to the district primary care physician. The district primary care physician recalls and performs a follow-up examination of the FLG-positive patient within 10 working days and completes Block 2 of the insert. When signs suggestive of tuberculosis are identified, the patient is referred to the third stage – the TB Dispensary Department of the CDH.

At this stage, a new documentation form is introduced – the insert in the outpatient medical record

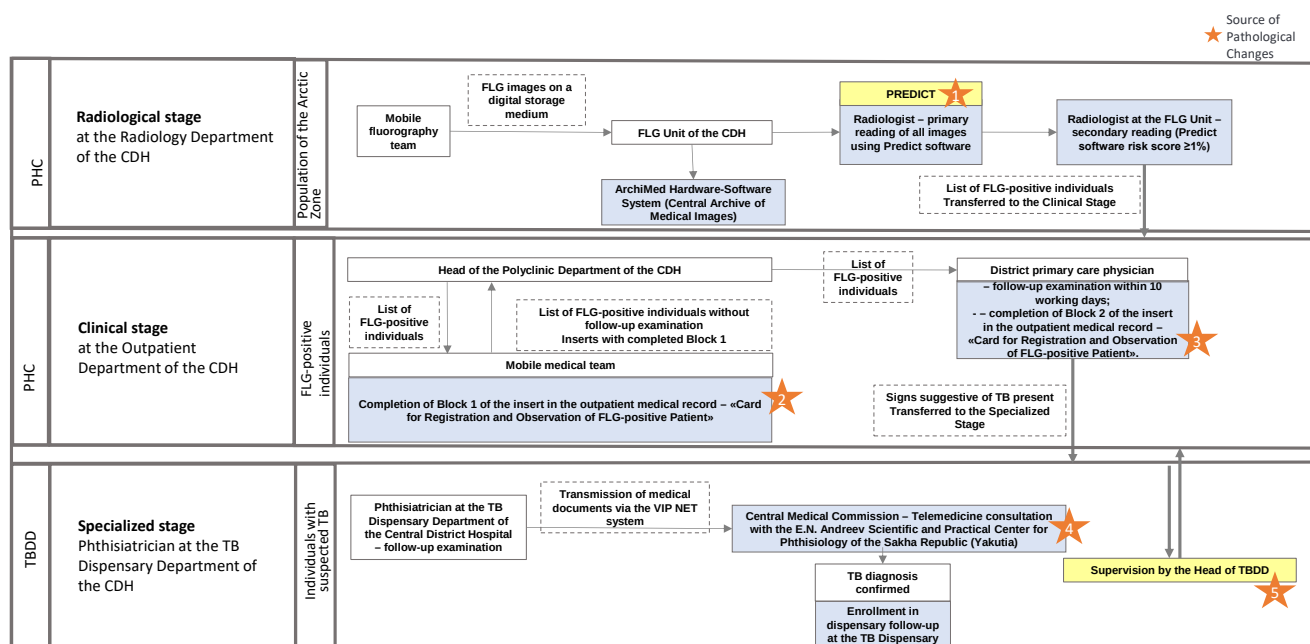


FIG. 2.

Algorithm for clinical and radiological screening of pulmonary tuberculosis based on the integrated use of information technology to improve detection and diagnosis in the Arctic zone of the Far North

“Clinical and Radiological Examination of FLG-positive Patient”, divided into two blocks: for the mobile medical team physician and for the district primary care physician. The insert for the mobile medical team includes patient identification information: demographic data, brief medical history, and the date of the most recent examination as reported by the patient. The insert for the primary care physician includes follow-up examination results and the final diagnosis.

At the third stage, individuals with suspected tuberculosis are referred for follow-up examination to the TB Dispensary Department of the CDH. The phthisiatrician at the TBDD transmits all patient examination results to the Scientific and Practical Center for Phthisiology via the secure ViPNet network for review by the Central Medical Commission using telemedicine technologies. When the diagnosis of tuberculosis is confirmed, the Central Medical Commission enrolls the patient in dispensary follow-up. Oversight of patient routing and compliance with the third stage procedures is the responsibility of the Head of the TB Dispensary Department of the CDH.

The Industrial Zone is characterized by more stable internet connectivity and better transport accessibility. Therefore, the Algorithm for this zone does not include the deployment of mobile teams (Fig. 3).

At the first stage, screening FLG examination of the entire population is conducted at the FLG Units of the Central District Hospitals. The radiologist uploads the FLG image database to the ArchiMed Central Archive of Medical Images and simultaneously

to the Predict software for primary reading. Following the receipt of fluorogram reading results from the Predict software, the radiologist performs secondary reading, prioritizing those images identified with a pathology probability of 1 % or higher. After completing secondary reading of all FLG images, the radiologist generates a list of FLG-positive individuals and transmits it to the second stage of the Model – the Deputy Chief Physician for Outpatient Care / Head of the Polyclinic Department of the CDH.

At the second stage of the Algorithm for the Industrial Zone, the Head of the Polyclinic Department of the CDH transmits the lists of FLG-positive individuals to the district primary care physicians, who perform a follow-up examination of the patient within 10 working days and complete the insert in the outpatient medical record – “Clinical and Radiological Examination of FLG-positive Patient”. When signs suggestive of tuberculosis are identified, the patient is referred to the third stage – the TB Dispensary Department of the CDH for follow-up examination.

At the third stage, the phthisiatrician transmits all patient examination results to the Scientific and Practical Center for Phthisiology via the secure ViPNet network for review by the Central Medical Commission (CMC) using telemedicine technologies. When the diagnosis of tuberculosis is confirmed, the CMC enrolls the patient in dispensary follow-up. Oversight of patient routing and compliance with the third stage procedures is the responsibility of the Head of the TB Dispensary Department of the CDH.

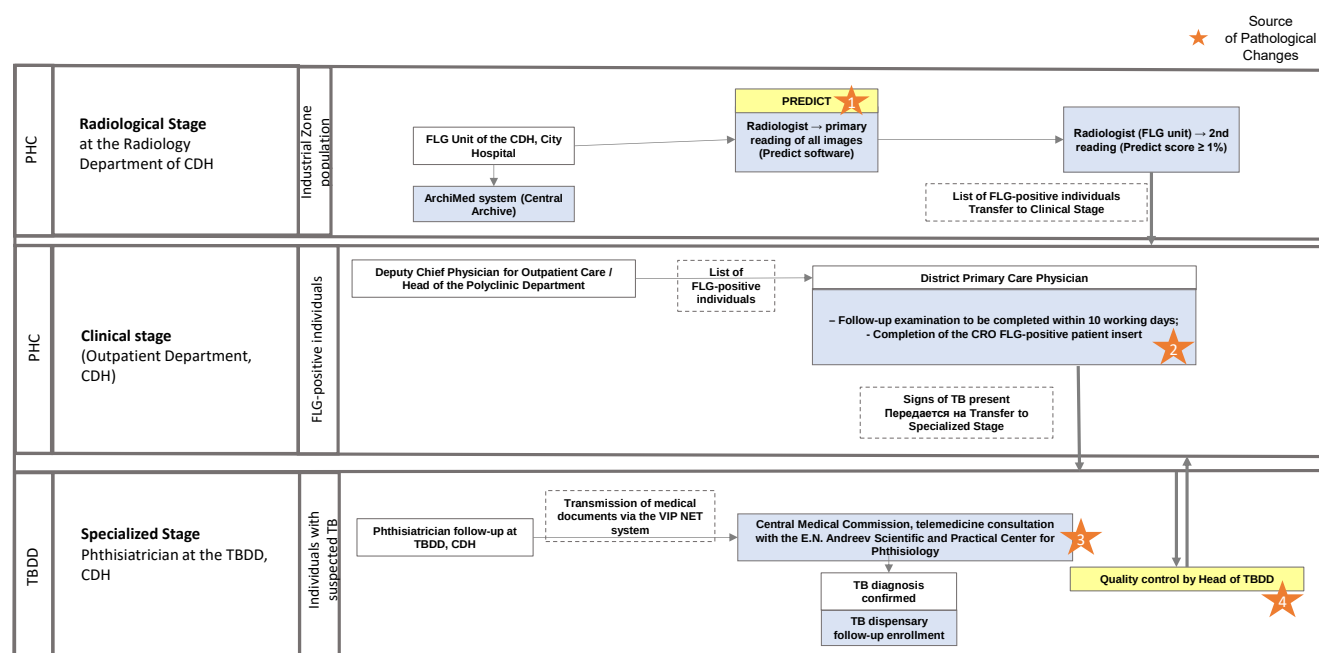


FIG. 3.

Algorithm for clinical and radiological screening of pulmonary tuberculosis based on the integrated use of information technology to improve detection and diagnosis in the Industrial zone of the Far North

At present, the Predict software continues to undergo pilot testing and refinement of artificial intelligence parameters to improve sensitivity and specificity.

Radiological images obtained during mass screening examinations are routinely reviewed by two radiologists to reduce the risk of missed pathology. Primary reading of the radiological image is performed immediately after the examination, taking 5–7 minutes per image. Secondary reading is performed either by a different radiologist or by the same radiologist after 24 hours. This system improves the detection rate of pathological changes to up to 99 %, but is time-consuming.

The use of AI eliminates the need for primary reading by a radiologist, reducing reading time to 1–2 seconds per image and increasing detection efficiency to 99.6 %. The radiologist performs only secondary reading of radiological images, and with AI assistance, reading efficiency increases to up to 100 %.

As a result of implementing the Organizational Two-Component Model with AI integration, the following objectives of the healthcare digitalization program are achieved: improved quality of pulmonary tuberculosis diagnosis; reduced examination time per patient; reduced workload on radiologists; and increased accessibility of medical care to the population.

DISCUSSION

The key achievement of this work is the development of a comprehensive Organizational Two-Component Model, in which digital tools perform strictly defined functions within the overall tuberculosis care system. The main process improvement has been achieved through clear regulation of stages and data flows. Automated primary triage through the upload of fluorograms to the Predict software replaces the labor-intensive primary reading by a physician, instantly identifying images with low pathology probability and prioritizing those requiring specialist attention. This represents not diagnosis, but an efficient triage system that optimizes specialist workload.

An important element of the Model Algorithms is centralization of expert review, which provides for mandatory secondary reading of images from risk groups by a radiologist at the core institution via the Central Archive of Medical Images. This approach successfully addresses the shortage of local personnel and standardizes evaluation criteria. End-to-end electronic routing ensures the generation of a digital list of FLG-positive individuals and its automatic transmission via secure network from the radiologist to the Head of the Polyclinic Department and then to the district primary care physician, eliminating data loss and delays inherent in paper-based document management.

Of particular note is the development of differentiated processes for different settings. The creation of two separate algorithms for the Arctic and Industrial Zones

demonstrates a systematic approach to problem-solving. For the Arctic Zone, the algorithm is supplemented by the deployment of mobile teams and a new documentation form, compensating for the lack of direct access to healthcare facilities. For the Industrial Zone with developed infrastructure, the algorithm operates in a more direct and rapid mode. Thus, the Predict software functions not as an independent diagnostic tool, but as a critical filter-accelerator at the entry point of the established clinical process. The reduction in diagnostic timeframes should be considered a consequence of comprehensive process optimization rather than merely the use of technological solutions.

Study Limitations

The presented algorithms have several limitations related to implementation stages and generalizability. Reliable operation critically depends on the uninterrupted functioning of all technological components, including the Central Archive of Medical Images, secure networks, and stable Internet connectivity. In the Arctic Zone, failure at any of these stages may paralyze the entire process. There is also a risk of operational errors, as the workload increases on the central hub – the radiologists at the core institution and healthcare organizers responsible for coordinating data flows.

The study documents improvement in performance indicators; however, to assess the ultimate effectiveness of the Organizational Two-Component Model, long-term data on epidemiological outcomes are required, which may only become apparent after several years of observation.

CONCLUSION

The conducted research confirms that early tuberculosis detection in sparsely populated territories remains a challenging task due to low population density and limited accessibility of traditional screening methods. The implementation of telemedicine technologies and digital tools may improve diagnostic coverage; however, their application in the Arctic and Industrial Zones requires adaptation to the specific characteristics of the territories and approaches to healthcare service organization.

Key unresolved aspects include optimization of patient routing, reduction of time to diagnosis, and improvement of radiological data interpretation accuracy, particularly under conditions of specialist shortages.

In this study, an Organizational Two-Component Model for tuberculosis detection using information technologies, including AI-based Predict software, was developed and piloted. The implementation of the Model resulted in a 3.2 % increase in fluorographic screening coverage, a reduction in diagnostic timeframes by 22.7–32.9 days, and a 2–4 times reduction in the number of patients without follow-up completed.

The use of artificial intelligence in fluorogram analysis provides high accuracy (up to 99.6 %),

while minimizing missed pathology and reducing the workload on radiologists. The developed Algorithms for the Arctic and Industrial Zones have demonstrated their effectiveness through the combination of telemedicine consultations, automated image analysis, and optimized patient routing.

The obtained results have significant clinical implications, as they improve the accessibility and quality of tuberculosis diagnosis in hard-to-reach regions and reduce the time from detection to treatment. The scientific value of this work lies in substantiating an approach that combines digital technologies with adapted organizational solutions for different socio-territorial zones. For further research, it would be beneficial to extend the pilot implementation of the Model to other regions with similar conditions, refine AI algorithms to improve specificity in differential diagnosis, and study the long-term impact of the implemented methods on tuberculosis epidemiological indicators.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

1. Borodulina EA. Issues of tuberculosis detection in general medical practice. *Doctor*. 2023; 34(2): 5–10. (In Russ.). [Бородулина Е.А. Вопросы выявления туберкулеза в общеврачебной практике. *Врач*. 2023; 34(2): 5–10.]. doi: 10.29296/25877305-2023-02-01
2. Guseynalieva VN. Improved detection of tuberculosis in primary health care and its impact on the incidence. *Tuberculosis and Lung Diseases*. 2020; 98(10): 41–46. (In Russ.). [Гусейналиева В.Н. Совершенствование выявления туберкулеза в учреждениях первичного медицинского звена и его влияние на показатель заболеваемости. *Туберкулез и болезни легких*. 2020; 98(10): 41–46.]. doi: 10.21292/2075-1230-2020-98-10-41-46
3. Sterlikov SA, Galkin VB, Maliev BM, Shirokova AA, Khorotetto VA, Mayzhegisheva AS. Impact of active case finding on treatment outcomes in adult pulmonary tuberculosis patients. *Tuberculosis and Lung Diseases*. 2021; 99(7): 33–40. (In Russ.). [Стерликов С.А., Галкин В.Б., Малиев Б.М., Широкова А.А., Хоротэтто В.А., Майжегисева А.С. Влияние активного выявления случаев туберкулеза на результаты лечения взрослых пациентов с туберкулезом легких. *Туберкулез и болезни легких*. 2021; 99(7): 33–40.]. doi: 10.21292/2075-1230-2021-99-7-33-40
4. Burtseva TE, Sleptsova SS, Gogolev NM, Afanaseva LN, Borisova EA, Korosteleva AV, et al. Features of medical care and medical-demographic indicators in the Arctic regions of the Republic of Sakha (Yakutia). *Yakut Medical Journal*. 2021; (1): 73–77. (In Russ.). [Бурцева Т.Е., Слепцова С.С., Гоголев Н.М., Афанасьева Л.Н., Борисова Е.А., Коростелева А.В. и др. Особенности медицинского обслуживания и медико-демографические показатели в арктических районах РС(Я). *Якутский медицинский журнал*. 2021; (1): 73–77.]. doi: 10.25789/YMJ.2021.73.20
5. Kalashnikov KN, Artamonov IV. Health care in rural areas: spatial and temporal aspects of accessibility. *Problems of Territory's Development*. 2020; 2(106): 120–132. (In Russ.). [Калашников К.Н., Артамонов И.В. Здравоохранение сельских территорий: пространственно-временные аспекты доступности. *Проблемы развития территории*. 2020; 2(106): 120–132.]. DOI: 10.15838/ptd.2020.2.106.9
6. Stupac VS, Manoshkina EM, Deev IA, Kobayakova OS, Bantyeva MN, Sokolovskaya TA. Climatogeographic background for organizing medical care for the Far North Russian Federation population. *Russian Journal of Preventive Medicine*. 2023; 26(12): 109–115. (In Russ.). [Ступак В.С., Маношкина Е.М., Деев И.А., Кобякова О.С., Бантьева М.Н., Соколовская Т.А. Климатогеографические предпосылки организации медицинской помощи населению районов Крайнего Севера в Российской Федерации. *Профилактическая медицина*. 2023; 26(12): 109–115.]. doi: 10.17116/profmed202326121109
7. Tsybikova EB, Zubova NA. Approaches to organization of respiratory tuberculosis detection when its prevalence is decreasing. *Tuberculosis and Lung Diseases*. 2019; 97(9): 33–39. (In Russ.). [Цыбикова Э.Б., Зубова Н.А. Подходы к организации выявления туберкулеза органов дыхания в условиях снижения его распространенности. *Туберкулез и болезни легких*. 2019; 97(9): 33–39.]. doi: 10.21292/2075-1230-2019-97-9-33-39
8. Korovka VG, Galkin VB, Panidi EA, et al. Potential of geoinformation technologies to improve the monitoring of socially significant infections outbreaks. *Russian Journal of Preventive Medicine*. 2021; 24(10): 713. (In Russ.). [Коровка В.Г., Галкин В.Б., Паниди Е.А., Кузнецов И.С., Бельтюков М.В., Соколов Е.Г. и др. Возможности геоинформационных технологий для улучшения качества мониторинга очагов социально значимых инфекций. *Профилактическая медицина*. 2021; 24(10): 7-13.]. doi: 10.17116/profmed2021241017
9. Morozov SP, Kokina DYU, Pavlov NA, Kirpichev YuS, et al. Clinical aspects of using artificial intelligence for the interpretation of chest X-rays. *Tuberculosis and Lung Diseases*. 2021; 99(4): 58–64. (In Russ.). [Морозов С.П., Кокина Д.Ю., Павлов Н.А., Кирпичев Ю.С., Гомболовский В.А., Андрейченко А.Е. Клинические аспекты применения искусственного интеллекта для интерпретации рентгенограмм органов грудной клетки. *Туберкулез и болезни легких*. 2021; 99(4): 58–64.]. doi: 10.21292/2075-1230-2021-99-4-58-64
10. Arzamasov K, Vasilev Y, Vladzimirsky A, Omel'yanskaya O, Shulkin I, Kozikhina D, et al. An international noninferiority study for the benchmarking of AI for routine radiology cases: chest x-ray, fluorography and mammography. *Healthcare*. 2023; 11(12): 1684. doi: 10.3390/healthcare11121684
11. Seah JCY, Tang CHM, Buchlak QD, Holt XG, Wardman JB, Aimoldin A, et al. Effect of a comprehensive deep-learning model on the accuracy of chest x-ray interpretation by radiologists: a retrospective, multireader mul-

ticase study. *Lancet Digit Health*. 2021; 3(8): 496-506. doi: 10.1016/S2589-7500(21)00106-0

12. Tyrylgina MA. *Health protection problems in the population of the Extreme North*. Novosibirsk: Nauka Publ.; 2008. (In Russ.). [Тырылгин М.А. *Проблемы охраны здоровья населения Крайнего Севера*. Новосибирск: Наука; 2008.].

13. *On the approval of the list of constituent entities of the Russian Federation and certain regions of the Russian Federation belonging to territories with low or high population density*. Order of the Government of the Russian Federation dated 25.05.2004 No. 707-R (as amended by orders of the Government of the Russian Federation dated 08.09.2004 No. 1165-r, dated 04.11.2004 No.

1397-r). (In Russ.). [Об утверждении перечня субъектов Российской Федерации и отдельных районов Российской Федерации, относящихся к территориям с низкой либо с высокой плотностью населения. Распоряжение Правительства Российской Федерации от 25.05.2004 № 707-Р (в ред. распоряжений Правительства РФ от 08.09.2004 N 1165-р, от 04.11.2004 N 1397-р).]. URL: <https://normativ.kontur.ru/document?moduleId=1&documentId=67386>

14. Pchelintsev Ya, Khvostikov A, Buchatskaia O, Nikiforova N, Shepeleva L, Prokopen E, et al. Robustness analysis of chest x-ray computer tuberculosis diagnosis. *Computational Mathematics and Modeling*. 2023; 33(4): 472-486. doi: 10.1007/s10598-023-09587-0

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