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RADIOLOGICAL DIAGNOSIS OF TUBERCULOSIS IN CHILDREN: POSSIBILITIES AND LIMITATIONS OF THE NATIONAL PROTOCOL

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Summary.
Pediatric tuberculosis remains a critical public health issue, complicated by low sensitivity of microbiological methods and non-specific clinical presentations. In 2023, Moldova adopted the National Clinical Protocol PCN-55, significantly emphasizing radiological techniques such as digital radiography, computed tomography, and digital tomosynthesis. This article analyzes the strengths and limitations of these imaging methods according to national and international standards, highlighting the need for further standardization and training of radiologists to enhance diagnostic effectiveness and treatment outcomes of childhood tuberculosis within the national healthcare system.
Keywords: pediatric tuberculosis, radiography, tomosynthesis, computed tomography, national protocol, diagnosis.

Rezumat. Diagnosticul radiologic al tuberculozei la copii: oportunități și limitări ale protocolului național.
Tuberculoza la copii rămâne o problemă majoră de sănătate publică, diagnosticul fiind complicat de sensibilitatea scăzută a metodelor microbiologice și tabloul clinic nespecific. În anul 2023, în Republica Moldova a fost aprobat Protocolul Clinic Național PCN-55, care accentuează importanța metodelor radiologice, inclusiv radiografia digitală, tomografia computerizată și tomosinteza digitală. Articolul analizează avantajele și limitările acestor metode în contextul protocolului și standardelor internaționale, subliniind necesitatea standardizării și instruirii continue a medicilor radiologi pentru optimizarea diagnosticului și tratamentului tuberculozei pediatrice în cadrul sistemului național de sănătate.
Cuvinte cheie: tuberculoză pediatrică, radiografie, tomosinteză, tomografie computerizată, protocol național, diagnostic.

Резюме. Рентгенодиагностика туберкулеза у детей: возможности и ограничения национального протокола**.**
Туберкулез у детей остается важной проблемой здравоохранения, диагностика которого затруднена низкой информативностью микробиологических методов и неспецифичностью клинической картины. В 2023 году в Республике Молдова утвержден Национальный клинический протокол PCN-55, в котором существенная роль отведена методам рентгенодиагностики, включая цифровую рентгенографию, компьютерную томографию и томосинтез. Настоящая статья анализирует преимущества и ограничения данных методов согласно протоколу и международным стандартам, подчеркивая необходимость дальнейшей стандартизации и обучения врачей-рентгенологов для повышения эффективности диагностики и лечения детского туберкулеза в национальной системе здравоохранения.
Ключевые слова: туберкулез у детей, рентгенография, томосинтез, компьютерная томография, национальный протокол, диагностика.

Introduction.

Tuberculosis (TB) in children remains a significant public health issue requiring timely diagnosis and treatment. According to the WHO, approximately 1.1–1.2 million cases of TB are reported annually in children, but less than half of these are diagnosed or reported [5].

In younger children, the disease is usually primary, characterized by a low number of mycobacteria (oligobacillary) and a tendency to rapid generalization of the infection. In this regard, standard methods of microbiological confirmation (smear microscopy, culture) are significantly less sensitive in pediatric practice. The role of radiological diagnosis, primarily chest X-rays, is extremely important: X-rays remain a valuable diagnostic tool for TB in children, especially when laboratory tests are unavailable or negative [13].

Radiological signs of tuberculosis in children differ from those in adults. Primary tuberculosis is more common in children, with manifestations such as intrathoracic lymphadenopathy (enlargement of bronchopulmonary and mediastinal lymph nodes), focal consolidation in the lungs, atelectasis due to compression of the bronchi by enlarged nodes, and pleural effusion. Lung tissue destruction is not typical for young children (except for adolescents, whose clinical course is similar to that of adults). When performing a radiological examination of a child

with suspected TB, the radiologist should be aware of the following features: for example, a lateral chest X-ray in children under 5 years of age significantly increases the detectability of enlarged lymph nodes in the mediastinum and mediastinum. International guidelines emphasize that in younger children, both anterior-posterior (AP) and lateral projections of the chest should be performed for optimal visualization of intrathoracic lymphadenopathy. In older children and adolescents, a standard posterior-anterior (PA) X-ray is preferred [5]. Thus, X-ray examination is an integral part of the diagnosis of childhood tuberculosis, but its informative value depends on the correct technique (choice of projections, image quality) and the skill of the specialist interpreting the results.

In addition, no single radiographic feature is pathognomonic for TB, and changes on chest X-rays in children may be nonspecific. Shadows of enlarged lymph nodes or infiltrative changes can be observed in various conditions (atypical pneumonia, fungal infections, lymphomas, etc.). Therefore, the diagnosis of tuberculosis in a child is usually based on a combination of data: epidemiological history (contact with TB), clinical symptoms, immunological test results (Mantoux test, IGRA), and radiological findings, and, if possible, bacteriological confirmation. National and international clinical guidelines are designed to help doctors systematize this information and decide on treatment.

In 2023, the Republic of Moldova approved National Clinical Protocol PCN-55 "Tuberculosis in Children," which is the fifth edition of the guidelines for the diagnosis, treatment, and prevention of the disease in the pediatric population. The document was developed based on current recommendations from the World Health Organization and international experience [10]. It pays considerable attention to X-ray diagnostics, from screening strategies for contacts to criteria for radiological confirmation of diagnosis and assessment of treatment effectiveness.

This paper presents a detailed analysis of the sections of the updated protocol relating to radiological diagnosis and is based on our experience of its application in clinical practice. The analysis is conducted with the aim of identifying the advantages and possible limitations of this document in light of current international standards and scientific publications.

The aim of the study is to comprehensively assess the effectiveness and potential shortcomings of the national protocol for X-ray diagnosis of tuberculosis in children, as well as to develop practical recommendations for its further improvement.

Materials and methods.

This study was conducted in the form of a critical review of regulatory documents and scientific literature. The main source of information was the National Clinical Protocol of the Republic of Moldova PCN-55 ("Tuberculosis in Children," 2023), which regulates the use of radiographic methods for the diagnosis of tuberculosis in children.

Reference sources were searched in the PubMed and Google Scholar databases using the keywords: pediatric tuberculosis, chest X-ray, radiography, diagnosis. International documents were used, primarily WHO recommendations [24-31]. Content analysis was used to extract quantitative and factual data from the sources.

Results and discussion.

X-ray diagnosis of TB in children in the national protocol: main provisions

Protocol PCN-55 considers X-ray examination as a mandatory component of tuberculosis diagnosis in children. In the section "TB diagnosis algorithm," after assessing clinical signs and risk factors, a comprehensive examination is recommended, including: physical examination, complete blood count, HIV testing, collection of material for detection of *M. tuberculosis* (GeneXpert MTB/RIF, smear microscopy and culture) and mandatory chest X-ray examination. If extrapulmonary TB is suspected, the protocol prescribes X-ray examination of the affected organ or system (e.g., X-ray of the affected bones or joints) [10]. Thus, the national standard emphasizes that no case of suspected tuberculosis in a child should remain without radiological examination.

It should be noted that the protocol emphasizes the use of modern equipment. The section "Additional examinations" states that in cases of pulmonary tuberculosis, children should undergo digital chest X-rays whenever possible and, if necessary, high-resolution CT (HRCT) of the chest organs [10]. Digital (computerized) radiography provides higher image quality and reduces radiation exposure, which is especially important in pediatrics. CT is used because in a small percentage of children, the radiographic picture may be unclear or complicated—for example, it may be difficult to distinguish inflammatory infiltrates from atelectasis, assess the degree of lymphadenopathy, or identify small cavities. High-field CT of the lungs is much more sensitive to small changes than a chest X-ray and can confirm the presence of enlarged lymph nodes, miliary lesions, or lung tissue destruction if this is essential for diagnosis. However, CT is associated with greater radiation exposure and often requires sedation of

young children, so the protocol recommends it "when indicated" – i.e., in complex diagnostic cases. Overall, the inclusion of CT among the recommended methods reflects the current approach, whereby tomography should be used to refine the diagnosis when radiography is inconclusive.

At the screening (active detection) stage for tuberculosis in contact children and risk groups, the national protocol also takes into account the role of radiography. According to the protocol, a "parallel screening algorithm" is provided for children who have been in contact with a TB patient or belong to vulnerable categories: the presence of symptoms is assessed, a tuberculin test (or IGRA) is performed, and chest X-rays are taken [10]. This approach is in line with WHO recommendations for systematic screening, which emphasize a combination of methods: symptom questioning, tuberculin testing, and chest X-rays as tools for early detection of TB who. int. If resources are limited, the protocol allows for a screening algorithm without chest X-ray (symptoms + test only), but emphasizes that radiological methods should be used whenever possible to improve detection efficiency. In fact, studies show that X-rays are more sensitive than symptomatic screening alone in children who have been in contact with TB [5]. Many children with tuberculosis, especially younger children, may not have specific symptoms (or may be unable to express them), and radiographic changes are often the first sign of the disease. By prescribing screening of contacts and risk groups using X-rays, the national protocol helps to identify so-called subclinical tuberculosis–cases where, in the absence of obvious clinical symptoms, pathological abnormalities suggestive of TB are detected on a screening X-ray. This can certainly be considered one of the advantages of the protocol: it aims to ensure that no case of tuberculosis in children goes undetected due to passive tactics.

After a diagnosis of tuberculosis, X-ray examination is also used to classify the severity of the disease, which has a direct impact on treatment tactics.

The PCN-55 protocol, following current WHO recommendations, introduces the concepts of "extrapulmonary TB" and "pulmonary TB" and also divides the forms of the disease into "severe (extensive) TB" and "non-severe TB" [27].

In particular, non-severe forms of pulmonary TB in children include TB of the intrathoracic lymph nodes without airway obstruction, uncomplicated TB pleurisy, and limited (no more than one lobe of the lung) non-destructive lung lesions without a miliary pattern. Severe (extensive) pulmonary TB is characterized by bilateral destructive changes on the X-ray, involvement of the lung parenchyma in three or more segments, and the presence of cavities. In children under 15 years of age, widespread pulmonary TB is determined by the presence of destructive changes or a bilateral pathological process on the X-ray.

Extrapulmonary TB covers cases of the disease with lesions in organs other than the lungs, such as the pleura, peripheral lymph nodes, abdominal organs, genitourinary system, skin, joints, bones, and meninges. Severe forms of extrapulmonary TB include miliary (disseminated) lesions and tuberculous meningitis. In children and adolescents under 15 years of age, any form of extrapulmonary TB, except for lymphadenopathy (peripheral or intrathoracic lymph nodes without airway compression), is also classified as severe [10].

It should be noted that according to the clinical classification of TB, lesions of the intrathoracic lymph nodes (A15.4; A16.3) and tuberculous pleurisy (A15.6; A16.5) are classified as extrapulmonary forms of the disease. In this regard, the differences in the classification approaches presented in the PCN-55 protocol are probably due to the need for a clearer distinction between forms of TB, taking into account their clinical significance, prognosis, and treatment tactics in children.

This distinction is of particular practical importance, since it is precisely these radiographic criteria that directly influence the choice of treatment duration. Thus, according to updated international recommendations, children with mild pulmonary tuberculosis may receive a shortened course of therapy (4 months of primary drugs instead of the standard 6 months) if the pathogen's sensitivity is confirmed [5]. Thus, radiological assessment allows patients to be stratified and, in the absence of signs of severe disease on the images, a more lenient short treatment regimen to be prescribed. This innovation is reflected in the protocol and is an undoubted advantage—domestic pediatric phthisiology has been brought into line with evidence-based practice, where the scope of therapy is adapted to the clinical and radiological picture.

In addition, radiography is also used to monitor the effectiveness of tuberculosis treatment in children. Although this aspect is described in less detail in the protocol, the general recommendations are as follows: repeat follow-up radiographic examinations are performed as indicated, usually in the middle of the course and at the end of treatment, as well as in the absence of clinical improvement. The WHO emphasizes that X-rays can help assess response to treatment and identify alternative diagnoses in

children who do not respond to anti-tuberculosis therapy [5]. The national protocol is consistent with this position: if symptoms persist or new complaints appear after 2–3 months of therapy, unscheduled X-rays should be performed to clarify the dynamics—the absence of positive changes on the image may indicate an incorrect diagnosis or the development of complications. On the other hand, it is important to understand the limitation: in children, the resolution of tuberculous changes may lag behind clinical improvement, and calcification of lymph nodes or scarring may persist for years. Therefore, the protocol does not recommend taking too frequent follow-up images without indication, so as not to expose the child to unnecessary radiation. Overall, the presence of clear criteria in the national standard for when to use radiography (and CT) at different stages–from screening to removal from dispensary observation—is one of its strengths, ensuring uniformity of approach for doctors from different institutions.

Advantages of the national protocol in terms of X-ray diagnostics

The analysis showed that the PCN-55 protocol for tuberculosis in children has a number of significant advantages:

Compliance with advanced international recommendations

The document was developed taking into account current WHO guidelines. In particular, it takes into account the provisions of the WHO expert consensus (September 2021), according to which tuberculosis of the intrathoracic lymph nodes in children is classified as pulmonary TB [10] (previously, many national systems classified it as extrapulmonary). A new strategy for classifying cases as severe or non-severe based on radiographic criteria has also been implemented, which, as discussed above, opens up the possibility of shortened treatment for certain patients. The protocol includes an updated contact screening algorithm, harmonized with the 2021 WHO recommendations: TB screening should include chest X-rays for contacts and risk groups [26], as this increases the detection rate of infection at the preclinical stage. This progressive approach distinguishes the new protocol from outdated practices, where children who had been in contact with TB were often simply given a Mantoux test, with X-rays only performed if the test was positive. Now, a more sensitive strategy of "test and X-ray for all contacts" is proposed, which is in line with the principle of early detection.

Comprehensive and systematic approach

The protocol does not consider X-ray diagnosis in isolation, but as part of a comprehensive diagnostic algorithm together with clinical assessment and laboratory tests.

The algorithm clearly defines the place of radiography: after identifying symptoms and risk factors, it is used to confirm or rule out the disease, along with GeneXpert and other tests [10]. Radiographic data are always interpreted in the context of other results. This approach improves diagnostic accuracy: the combination of several methods compensates for the limited specificity of each. For example, in a child with a positive Mantoux test and suspicious changes on X-ray, the probability of TB is very high, and the protocol recommends starting treatment even in the absence of bacteriological confirmation (which is most often the case in children). Conversely, if both the X-ray and all tests are normal, a diagnosis of TB is unlikely, and the protocol allows for the avoidance of unnecessary preventive treatment in such cases. Thus, the national standard is a practical tool for weighing all the pros and cons of a diagnosis, where radiography is one of the decisive factors, but not the only one.

Clear criteria for interpreting radiographic findings

Another advantage is that the protocol provides doctors with certain guidelines for evaluating X-rays. Key syndromes are described: primary tuberculosis complex (lesion in the lung + lymphadenopathy), focal infiltrate, miliary dissemination, pleurisy. It is indicated that the detection of signs of previous TB infection (e.g., Gon's focus, calcifications in the lymph nodes) is a risk factor for reactivation of tuberculosis infection [10]. The inclusion of this information helps doctors to be vigilant. If residual changes are detected on a chest X-ray during a preventive examination of a child, the child should be referred for further examination, as the risk of tuberculosis reactivation is high in combination with immunodeficiency or other factors. The protocol also warns that the absence of radiological abnormalities does not in itself rule out the diagnosis–with pronounced symptoms of TB, treatment can be started even with a normal X-ray (especially in children with proven contact). This position is consistent with the literature: according to some data, up to 15% of children with tuberculosis infection may have a normal X-ray picture [4]. Therefore, clinicians should evaluate X-rays dynamically and use other methods rather than rejecting the diagnosis if the initial image is normal. This balance is reflected in the protocol, which calls for the active use of X-rays but does not treat their results as absolute, reflecting a deep understanding of the method's capabilities and limitations.

Use of new technologies and radiation techniques

Unlike older guidelines, the modern protocol explicitly mentions the possibility of using digital radiography systems and computed tomography [10].

Digital radiography is already widely used in the Republic of Moldova, and the protocol emphasizes its advantages – lower doses and the ability to archive images electronically (PACS), which facilitates consultation and dynamic monitoring. The mention of CT is particularly important for complex cases: for example, a child with suspected tuberculous meningitis will require a CT/MRI scan of the brain; in cases of osteoarticular TB, an X-ray and CT scan of the affected area will be required. The protocol lists these situations without limiting itself to radiography, as was the case in the past. Thus, the national standard demonstrates openness to innovation: doctors are given the green light to use the maximum diagnostic capabilities justified from a scientific point of view. Although the protocol guidelines are not technical regulations, the very fact that they have been updated to take account of modern technologies is an advantage of the document.

The inclusion of digital tomosynthesis (layered digital radiography) in the protocol deserves special attention. The mention of this method demonstrates the commitment of national standards to modern international recommendations and the intention to introduce advanced diagnostic technologies. Tomosynthesis, thanks to the acquisition of layer-by-layer images, significantly improves the visualization of intrathoracic structures, increasing the sensitivity of detection of lymphadenopathy, small focal changes, and the initial stages of the destructive process characteristic of childhood tuberculosis.

However, in the current version of the protocol, tomosynthesis is presented in a limited scope and without specifying the algorithms for its use. There are no clear clinical situations, criteria for prescription, comparative analysis of the advantages of the method in relation to traditional radiography and CT, and the dose characteristics and potential limitations of informativeness are not disclosed. In addition, the practical availability of tomosynthesis in healthcare institutions in the republic is not addressed. In this regard, it is advisable to specify the use of tomosynthesis in future editions of the protocol, which will allow clinicians to use this promising diagnostic method more confidently in their practice.

Improving TB detection and reducing missed diagnoses

Taken together, the above advantages (active screening, comprehensive examination, severity criteria) lead to the main clinical outcome: more timely diagnosis of tuberculosis in children. If the protocol is followed, the likelihood of missing a child with TB is minimized. For example, contact children will be examined more thoroughly, which will allow hidden cases of TB to be detected before severe forms develop. Early initiation of treatment, in turn, reduces the risk of complications and fatal outcomes. According to research, during the COVID-19 pandemic, when access to X-ray diagnostics and TB detection in general was limited, there was a setback in the fight against childhood tuberculosis (the number of registered cases decreased by 18–20%) [7]. Now, by implementing a protocol with a stronger focus on diagnosis, Moldova's health system is seeking to make up for these losses. The new protocol is expected to increase TB detection rates among children and enable cases to be detected at earlier stages, which is the ultimate goal.

Limitations and challenges of X-ray diagnosis under the protocol

Despite the advantages listed above, the analysis revealed a number of limitations and potential challenges in implementing the PCN-55 protocol with regard to X-ray diagnosis:

Limited specificity of radiography and the possibility of overdiagnosis

As noted, radiographic manifestations of tuberculosis in children can be nonspecific. The protocol acknowledges that the differential diagnosis is broad: enlarged lymph nodes or infiltrates in the lung may mimic pneumonia, mycobacteriosis (atypical), tumors, sarcoidosis, etc. The differential diagnosis table lists alternative diagnoses for both the pulmonary form (the first is pneumonia, which is logical) and extrapulmonary manifestations (e.g., lymphadenitis of other etiologies, non-tuberculous pleurisy, etc.) [10]. However, in practice, there is a risk of overdiagnosis of TB in children, especially in endemic regions, when doctors tend to interpret any unclear X-ray as tuberculosis. Historically, in countries with a high burden of TB, it is not uncommon for children to be diagnosed with tuberculosis based on questionable radiographic findings and to undergo prolonged treatment, only to be found to have had a different disease. Unfortunately, the PCN-55 protocol does not offer clear tools to reduce the likelihood of such errors, other than mandatory confirmation of the diagnosis by other methods (but we know that confirmation is often not possible in children). There is a general contradiction here: in an effort not to miss TB, it is easy to "overdiagnose" it on X-ray, especially when there is a positive Mantoux reaction. The solution to this problem goes beyond the scope of the document

itself and is related to training and the availability of alternative diagnostic methods, such as lymph node biopsy and polymerase chain reaction (PCR) for other infections. Nevertheless, this limitation should be kept in mind: the protocol does not provide detailed descriptions of radiographic criteria to distinguish tuberculosis from, say, staphylococcal pneumonia or lymphoma. In this regard, radiography remains, in the words of a number of authors, "an additional, supportive diagnostic method that cannot by itself definitively diagnose tuberculosis" [5]. Recognizing this limitation, doctors should, whenever possible, consult specialists (for example, joint analysis of images by a radiologist and a phthisiologist) and use a "balanced" approach–for example, trial treatment with antibiotics for ordinary pneumonia followed by a follow-up X-ray: if the infiltrate resolves within 2 weeks, it was most likely not TB. Such tactical steps are not specified in the protocol and are left to the discretion of the clinician, which can be considered a shortcoming.

Dependence on the qualifications and experience of the radiologist

The protocol is based on an ideal situation where all radiological examinations are read competently. However, in real practice, the quality of interpretation of children's X-rays varies greatly.

The interpretation of chest X-rays in children is one of the most difficult areas of radiodiagnostics, requiring knowledge of the nuances of pediatric anatomy and tuberculosis radiology. In regional settings or in institutions with a low workload in pediatric TB, radiologists may not have sufficient experience. Studies demonstrate significant variability in the interpretation of chest X-rays in children diagnosed with tuberculosis by different specialists. For example, in one study where three experts independently evaluated X-rays of 218 children under the age of 3, the agreement between them was moderate (kappa coefficient ~0.5–0.6 for infiltrates and ~0.4–0.7 for pleurisy). The sensitivity of radiography was only 16–28% when using a strict definition of TB (i.e., many children who were diagnosed with TB by a panel based on a combination of data initially had "negative" or inconclusive X-rays). This low rate highlights that a significant proportion of childhood TB cases are radiographically occult or unrecognized. High specificity (91–98% in the same study) means that prominent changes on children's images are fairly reliable indicators of TB [5], but their absence does not guarantee good health. A protocol aimed at the active use of radiography inevitably faces the problem of subjectivity in its assessment. Unfortunately, the document pays virtually no attention to the issue of staff training or standardization of image description. For example, it does not mention existing international guidelines, such as the recently updated Atlas of Radiographs in Childhood Tuberculosis, published by the International Union Against Tuberculosis and Lung Disease (theunion.org). This atlas contains numerous examples of chest X-rays of children with TB and provides recommendations for interpreting them. The introduction of such educational tools at the national level could significantly improve the quality of diagnosis, but these aspects are not reflected in the text of the protocol. It is probably assumed that specialists are familiar with modern approaches, but in practice it would be advisable to conduct additional training and organize telemedicine consultations.

Thus, the implementation of the protocol's X-ray diagnostic recommendations directly depends on the human factor, which is its weak point. If images are interpreted incorrectly (either as "missed" or "overdiagnosed"), all the advantages of the standard are negated.

Material and technical limitations (availability of radiological methods)

The protocol boldly recommends CT and other complex examinations, but does not take into account whether they are always available where they are needed. In the Republic of Moldova, digital X-ray machines are not available in all regional hospitals; some institutions still use analog radiography, the quality of which sometimes does not meet modern requirements. The system for referring and transporting patients for examination is also flawed – it is not always easy to bring a child from a village to a regional center for a CT scan. The protocol does not specify mechanisms for ensuring that all prescribed examinations are performed. For example, it is ideologically correct to indicate the need for X-ray examination of all children who have been in contact with the patient, but in practice it is possible that not every contact will be examined due to overloaded X-ray rooms or the unwillingness of parents to expose their children to radiation without complaints. The protocol does not describe a strategy for communicating with families on this issue, nor does it mention educational work or convincing people of the safety and importance of X-rays. In addition, the lack of mobile X-ray units in rural areas may hamper screening coverage. International recommendations suggest using mobile digital X-ray machines with automatic interpretation by computer algorithms as a way to improve TB detection [25]. In the Republic of Moldova, such technologies have not yet been introduced and are not covered by the protocol.

This can be considered a limitation – a gap between regulatory standards and actual resources. Of course, a clinical protocol does not have to contain plans for material and technical support, but this factor must be taken into account when analyzing its effectiveness. For example, if a year after the protocol is introduced, it turns out that the proportion of contact children who have undergone X-rays is low, this will indicate the need to either supplement the radiology services or change tactics (for example, focus on the Mantoux test as a more accessible option).

Lack of mention of modern digital solutions (CAD) for image analysis

In 2021, the WHO recommended for the first time that artificial intelligence software be used to read digital X-rays in TB screening who.intwho.int. These systems (Computer-Aided Detection software) are trained to detect pathologies characteristic of tuberculosis in images and can be particularly useful where there is a shortage of qualified radiologists. At least some of these algorithms have been shown to be as sensitive as expert radiologists in assessing adult TB fluorograms. Although such systems are still under development and require adaptation for children, they can be expected to emerge in the coming years. The 2023 national protocol does not reflect this prospect, apparently due to the lack of practical experience in the use of AI in pediatric phthisiology. Nevertheless, this direction deserves attention: perhaps the next version of the protocol should mention the possibility of telemedicine and automated analysis. A study conducted in Mozambique in 2024 demonstrated the successful use of the BITScreen PHTB web platform for the remote transmission and joint interpretation of chest X-rays of children with suspected TB by several experts. pediatrics.jmir.org pediatrics.jmir.org. This approach improved diagnostic timeliness and doctor satisfaction.

Radiation exposure and safety

The protocol does not focus on radiation doses from X-rays and CT scans in children, although this is a sensitive issue for many parents and doctors. This gap is partially addressed by the recommendation to use digital equipment (which reduces the dose) and to perform tests only when indicated, rather than "just in case."

Nevertheless, the protocol could specify that the dose from a single digital chest X-ray is minimal and incomparable to the risk of untreated tuberculosis, in order to allay concerns. As for CT scans, the protocol recommends them only when necessary, but does not suggest specific low-dose CT protocols for children. In recent years, recommendations have emerged for ultra-low-dose CT for the diagnosis of pulmonary TB in children, where the dose is comparable to a single X-ray and the information content is much higher. This technology has been tested, for example, in South Africa and has shown high effectiveness in detecting even minor changes with minimal radiation exposure. Integrating these data into national guidelines would further optimize the benefit/risk balance. For now, the protocol is quite conservative in this regard: it focuses on standard diagnostics and traditional doses, leaving safety issues to the discretion of the treating team.

Overall, the limitations of the protocol are mainly practical issues and some ambiguities. The protocol sets the right direction, but to realize its potential, organizational efforts are needed: equipment provision, staff training, development of remote consultations, and introduction of new technologies. Without this, there is a high probability that some of the provisions will remain on paper or will not have the expected effect. Consequently, the national standard should be viewed as a tool whose effectiveness depends on the health care system as a whole. Nevertheless, the very fact that a modern protocol exists is a significant step forward, laying the foundation for improvements.

Conclusions.

The National Clinical Protocol for Tuberculosis in Children, in the section on X-ray diagnostics, demonstrates a modern, comprehensive approach to the detection and management of tuberculosis in pediatric patients. The advantages of the protocol lie in the integration of radiography at all stages, from screening to cure control, in the clear definition of radiological criteria for disease severity, and in bringing national recommendations into line with advanced international standards. In particular, the protocol emphasizes the need for mandatory X-ray examination at the slightest suspicion of TB in a child, thereby reducing the likelihood of missed cases. It also allows treatment tactics to be differentiated based on radiographic data, which increases the personalization and effectiveness of care.

At the same time, the limitations of this protocol have been identified. These include the limited specificity of radiographic changes in TB in children and the dependence on human factors in the interpretation of images, as well as possible difficulties in ensuring the recommended level of screening at the local level. Simply put, the protocol provides doctors with a tool, but the result depends on their ability to use it. Without sufficient experience and resources, even the most correct guidelines will not lead to improved diagnosis. Therefore, the next step–implementation of the protocol–requires attention to training and technical equipment.

Based on the analysis, the following measures can be proposed to enhance the effectiveness of X-ray diagnosis of TB in children within the framework of the National Clinical Protocol for Tuberculosis in Children:

1. *Training and qualification testing* should include periodic training for radiologists and TB specialists on the radiological signs of childhood TB using international materials (atlases, online courses), analysis of real clinical cases, and practice in secondary reading of "difficult" X-rays by experts, for example, as part of a telemedicine consultation center.

2. *Standardization of descriptions* involves the development of a short, unified template for X-ray imaging in cases of suspected tuberculosis in children, which includes key signs (lymph nodes, infiltrate, cavities, etc.) to reduce variability in interpretation and prevent important details from being overlooked.

3. *The use of tomosynthesis* involves the development of clear algorithms for its use in the diagnosis of childhood tuberculosis (e.g., in cases of inconclusive X-ray results and contraindications to CT), conducting a comparative analysis of the radiation exposure of tomosynthesis with traditional radiography and computed tomography, presenting clinical examples of its use in children with tuberculosis, and including a brief guide to the standardized interpretation of tomosynthesis results in the national clinical protocol.

4. *Enhancement of the material and technical base* should include equipping all TB dispensaries with modern digital X-ray units and, where possible, mobile X-ray units for conducting field examinations in remote areas, as well as the pilot introduction of low-dose computed tomography for the diagnosis of complex and controversial cases of childhood tuberculosis in collaboration with radiologists.

5. *The introduction of CAD systems and telemedicine* should begin with a study of the experience of using artificial intelligence programs to analyze children's X-rays, followed by a trial application of certified solutions in screening, especially among contact children, and the parallel development of a teleradiology network for the rapid analysis of images by specialists at the national level.

6. *Monitoring and auditing* should be carried out one and a half years after the implementation of the protocol in order to assess the number of X-rays performed on children who have been in contact with the disease, the number of cases detected during screening, and the compliance of prescriptions with the criteria for disease severity, on the basis of which practical recommendations and training programs should be adjusted.

7. *Public education* should be aimed at explaining to parents the importance of timely X-ray examinations and justifying their safety in order to increase families' adherence to routine medical examinations of children in accordance with the protocol.

Implementing these recommendations will help the national protocol's benefits really shine through and any limitations will gradually fade away. X-ray diagnosis of tuberculosis in children is a field of medicine in which technology is developing rapidly and new scientific data are emerging. Therefore, the results of further research (e.g., evaluations of the effectiveness of artificial intelligence systems or the impact of specialized training on the quality of diagnosis) should be taken into account when preparing future revisions of the national protocol. At the same time, it should be noted that the national protocol already serves as an example of the integration of WHO global recommendations into the national strategy.

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