Optimizing the Use of Radiological Methods of Diagnosis at Examining Children and Adolescents for Tb

Shepeleva L.P., Tyurin I.E., Kravchenko A.F., Karymova L.E.

Abstract

The authors proved high informative content of the computed tomography (CT), on the basis of the study of diagnostic informative content of radiographic research methods used in the survey of children and adolescents on primary pulmonary tuberculosis. CT diagnostic significance indicators exceed informative content of traditional radiographic techniques (radiography and linear tomography) in 2-2.5 times. A comparative assessment of radiation doses received during conventional radiological methods and CT is given. The authors revealed the dependence of the received radiation dose from the age, the highest radiation burden falls on young children and adolescents. In the result of the research, a high radiation dose at linear tomography at low diagnostic informative content was defined, thus indicating the need to abandon this method at testing children and adolescents to primary tuberculosis, in favor of CT.

Keywords: diagnostic informative content, radiation dose, x-ray methods, children and adolescents.

Introduction

In concordance with the WHO reports, diagnostic imaging methods play important role in the choice of adequate therapy, and these methods must be made accessible wherever there is a need in them. But the responsibility required to prevent an unnecessary use of these methods is at least as important.

In foreign countries, the efficiency of radiologic diagnosis is often assessed based on the so called 3D principle (diagnosis, dose and dollar) [16]. Following the contemporary understanding of radiation safety, any radiologic examination must be both useful, and harmless, or in other words, the expected benefit must at least outweigh possible risk.

Chest x-ray is the most often performed x-ray procedure over the world, making 50% of all the radiologic examinations [13]. In tuberculosis (TB) management, radiologic examinations are indispensable in determining the disease site and stage. The most common clinical form of TB in children is intrathoracic lymphadenopathy, which means, that the diagnosis is aimed at timely detection of TB infection in these particular organs, and the latter has a great significance in terms of prevention of disease complications, spreading or progression to chronic disease [3,8].

In accordance with the current regulations on the organization of regular medical checkup and registration of TB patient cohorts by anti-TB institutions (Russian Federation Health Ministry Order no. 109 “On improvement of tuberculosis preventive measures in the Russian Federation” dated March 21, 2003), the coverage and frequency of x-ray examinations among children and adolescents are based on the use of standard examination package, which includes chest x-ray and linear tomography of mediastinum.

Conventional chest x-ray remains the basic method of primary examination of thoracic organs, due to its rather small radiation exposure, low cost and fairly high diagnostic value, compared to other radiologic imaging methods. Effective dose for chest x-ray in adult patients is 0.1 (digital detector) mSv to 0.4 (photographic film) mSv, according to various authors [7,4].

Effective dose equivalent (EDE) is a conventional notion, designating the dose of uniformly distributed radiation, which corresponds to the dose of actual radiation received by a certain organ (sum of organs) in terms of risk for late effects (measurement unit is a Sievert). Average EDE caused by radiation for medical purposes is estimated as 1.5 mSv/year. Roughly speaking, exposure of 1 million population would result in approximately 37.5 to 56.3 diseases, 18.75 deaths, or 6 congenital abnormalities [12,15].

Linear tomography is a body section radiography method used as a conventional radiologic exam method in 10-15% of patients (in pediatric TB patients performed significantly more often: one in two patient is irradiated at least once a year), to refine the chest x-ray findings on abnormal macro-zones in lung tissue, hilum and mediastinum. Using standard chest x-ray and linear tomography, abnormalities in the intrathoracic lymph nodes can be diagnosed effectively only if the lymph nodes are markedly enlarged [2,5,9,17].

According to R.V. Stavitsky (1994), EDE for longitudinal linear tomography is higher than the EDE for chest x-ray or even fluoroscopy [13].

Today, using computed tomography (CT), which is currently recommended as an adjunctive method in cases suspected for minor forms of intrathoracic lymph node TB, it is possible to determine exactly the abnormalities in all groups of lymph nodes or lung tissues, to assess correctly the morphologic patterns in the infected lymph nodes, to describe the localization, extent and stage of the infection.

As it follows from published reports, routine CT in pediatric TB usually shows multiple calcified lymph nodes sized 0.2 to 0.5 sm. in 74.6% of cases. This is true even for latent tuberculosis infection, signalizing that a good diagnosis in intrathoracic lymph node TB is not achieved by means of standard radiologic examinations [1,10,11].

CT is a radiologic imaging method of high diagnostic value, but is associated with relatively high radiation doses. Alternative opinions occur in the literature. Studies conducted in the Russian Scientific Center of Roentgenoradiology have shown that deleterious effect from irradiation during CT was significantly lower, than during conventional longitudinal linear tomography [6].

Relative disadvantage of CT is its high cost, compared to conventional radiologic imaging methods, which limits its wider use.

As far as radiologic diagnosis involves ionizing irradiation, its use in pediatrics must be for good reasons, because children are more sensitive to radiation, which can disrupt normal development. According to F. Stive (1988), effect of ionizing radiation can manifest as general developmental delay, suppression of brain function, bone growth plates, liver function, blood, immune and endocrine systems [18].

All in all, chest x-ray, linear tomography and CT as methods of thoracic organ imaging are unequal in their diagnostic values, radiation exposure and cost. Knowledge of the capacities and feasibility of each method or their combination is both important and crucial, and it is the specialists in radiologic diagnosis who must act as experts in wise use of diagnostic methods and choice of optimal patient examination strategy [14].

Aim: to optimize the use radiologic imaging methods in examining children and adolescents for TB, based on diagnostic value of the methods and radiation exposure.

The following **tasks** were formulated to achieve the aim:

1. To assess the diagnostic value indicators (sensitivity, specificity, efficiency) for conventional radiologic imaging methods (chest x-ray, linear tomography) and CT in detection of intra thoracic lymph node TB among pulmonary TB patients.

2. Determine radiation doses for children and adolescents using different radiologic chest imaging methods (chest x-ray, linear tomography, CT) and either reference or dosimetry-derived effective doses.

Material and methods

To calculate the diagnostic value of conventional methods and CT, we used clinical radiologic data from 221 pediatric patients, who were examined in the Pediatric Regular Medical Checkup (Dispensary) Department of the Research & Practice Center for TB, and 374 pediatric patients from T.P.Dmitrieva Republican Pediatric TB Sanatorium.

Optimal choice of radiologic imaging methods to examine children and adolescents for primary TB of chest organs was made based on calculation of the diagnostic value of each method, including:

- Diagnostic sensitivity (percent of cases tested positive among patients with TB);
- Diagnostic specificity (percent of cases tested negative among patients without TB);
- Diagnostic efficiency (mean value between sensitivity and specificity);
- Positive predictive value (probability of the presence of TB in cases tested positive);
- Negative predictive value (probability of the absence of TB in cases tested negative).

For the purposes of dose load calculation, patients were divided to 4 age groups: 0-3, 3-7, 7-14 and 14-17 years (50 patients in each group). Dose load was determined using two calculation methods: reference dose-based and dosimetric.

For reference doses we used mean dose values for each of the radiologic imaging methods, developed by the Dosimetric Research Laboratory of the Russian Scientific Center of Roentgenoradiology and Moscow Technical Engineering Institute.

Reference doses provide very approximate effective dose values, due to the lack of account for patient size variability and the specific technical characteristics of the imaging equipment.

Dosimetric calculation of radiation doses was based on DAP meter readings.

Chest x-ray and linear longitudinal tomography were performed with Multix Pro system manufactured by Siemens, equipped with KermaX plus DDP dosimeter for determination of effective dose. DAP (μGy·m^2) and air radiation field meter readings were measured independently of the distance between the x-ray tube and the patient.

Than the DAP value (μGy·m^2) is conversed to age-specific effective radiation dose (E), using the formula:

$E = F \cdot K_{d,\ \mathrm{mcSv}}$, where

F stands for DAP, cGy sm^2;

K_d stands for conversion coefficient to age-specific effective radiation dose, depending on the radiologic exam method used, plane, imaging size, source to skin distance, x-ray tube kilovoltage, mcSv/(cGy sm^2).

Mean age-specific conversion coefficients for effective doses are given in the Standard Procedures MUK 2.6.1.1797-03 "Monitoring the effective patient dose in medical X-ray studies".

CT was performed using “Somatom Emotion Duo” dual-rows spiral scanner (Siemens). Effective dose was calculated using the calculation method developed by the Federal Radiologic Center (Saint-Petersburg Research Institute for Radiologic Health), Radiological Health Department of the Russian Medical Academy of Postgraduate Education, Russian Federation Health Ministry Department of State Sanitary-Epidemiological Surveillance, Research & Practice Center for Medical Radiology and ZAO (Joint Stock Company) “Meditsinskaya tekhnologiia” (Standard Procedures MUK 2.6.1.1797-03).

Computer Tomography Dose Index (CTDI) is used to characterize source axis dose distribution in the air or absorbed dose distribution per 1 scan. Next, effective doses are derived using conversion coefficients. CTDI values depend on physical technical equipment parameters (tube voltage, filtration, scan thickness etc.) and are proportional to exposure values (amount of electricity) *mAc*. Then, DLP_{i} (mGy · sm) is determined:

$E_i = e_{DLP} \cdot DLP$, where

e_{DLP} – conversion coefficient (mSv · mGy^{-1} · sm.$^{-1}$) for each anatomic slice i, normalized for standard phantom-derived DLP value.

Effective dose values in children are smaller due to small body size. To calculate DLP in children, 16 sm. diameter phantom is used, irrespective of the body region studied. Table 1 shows conversion coefficients (e_{DLP}) for children of different ages.

Table 1

Age-specific conversion coefficients for conversing *DLP* values for 16 sm diameter phantom to effective doses in children

Examination area	e_{DLP} for adults, $mSv \cdot mGy^{-1} \cdot sm$	Age-specific conversion coefficient (years)					
		>15	15	10	5	1	0
Head	0.0023	1.0	1.2	2.0	3.2	5.1	9.5
Trunk	0.0081	1.0	1.2	1.8	2.6	4.0	7.9

Results

During the phase 1 of the study, we calculated diagnostic values of conventional radiographic methods (chest x-ray, linear tomography) in 221 patients, who were examined in the Pediatric Regular Medical Checkup (Dispensary) Department of the Research & Practice Center for TB. After complete clinical radiographic examination, 53 out of total number of patients examined had localized active TB and residual post-TB alterations in the lungs and intrathoracic lymph nodes (true positive cases). In 43 patients, localized TB was excluded after complete clinical radiographic examination (true negative cases). In 69 patients with lung and hilar abnormalities detected by conventional methods, additional CT examination coupled with laboratory tests did not confirm the presence of localized TB (false positive cases). On the contrary, 56 patients with supposedly absent TB in the lungs and intrathoracic lymph nodes based on conventional methods, CT and laboratory tests established the presence of localized TB (false negative cases).

Radiologic exam results from 374 patients examined in the T.P.Dmitrieva Republican Pediatric TB Sanatorium in 2013 were used to determine diagnostic value of CT. After analyzing all clinical and radiological data, localized TB in various progression stages and post-TB alterations were found in 72 out of 374 patients (true positive cases). After the comprehensive clinical and radiological examination including CT, localized TB was excluded in 282 patients (true negative cases). In 18 patients, in whom CT showed the presence of lung and mediastinal abnormalities, clinical laboratory test results did not confirm the localized TB (false negative cases). 2 patients with apparently normal baseline CT scans, in whom localized TB was excluded based on laboratory results, dynamic CT examination revealed calcifications in the intrathoracic lymph nodes (false negative cases). Based on these findings, we calculated diagnostic values for each radiologic imaging method (Table 2).

Table 2

Comparison of diagnostic values of radiologic imaging methods in children and adolescents during establishing the diagnosis of primary TB of the respiratory organs

Method of radiologic examination	Sensitivity	Specificity	Efficiency	PPV	NPV
Plain chest x-ray + linear tomography	48%	38%	43%	43%	43%
CT	97%	94%	95%	80%	99%

Apparently, CT showed the highest diagnostic value in diagnosing TB-induced alterations in the lungs and intrathoracic lymph nodes. Diagnostic values of conventional radiographic methods were lower by a factor of 2-2.5.

During the phase 2 of the study, we assessed radiation exposure in 200 patients from various age groups, who were examined for primary TB using different radiologic imaging methods. Results are shown in Table 3.

Table 3

Dose loads in children and adolescents during chest organs examinations performed with different imaging methods and using either reference radiation doses or DAP meter derived doses

Method of radiologic examination	EDE, mSv / scan							
	Mean age							
	0-3 (n=50)		3-7 (n=50)		7-14 (n=50)		14-18 (n=50)	
	Dose calculation		Dose calculation		Dose calculation		Dose calculation	
	Reference doses	Dosimetry	Reference doses	Dosimetry	Reference doses	Dosimetry	Reference doses	Dosimetry
Chest x-ray	0.03	0.04	0.05	0.03	0.07	0.03	0.10	0.05
Linear tomography	1.14	0.20	1.02	0.15	1.38	0.15	0.90	0.23
CT	1.7	0.77	1.7	0.66	2.1	0.76	2.8	1.11

Concluding from published reports, effective doses calculated based on reference doses are too approximate, and due to impossibility to account for all physical and technical factors the margin of error can reach ±150-250%.

Age-specific effective doses for posterior-anterior chest x-ray ranged from 0.03 to 0.10 mSv (based on available reference doses) and from 0.03 to 0.05 mSv (based on DAP meter readings).

Alterations in intrathoracic lymph nodes were detected by means of standard chest x-ray alongside with linear longitudinal tomography. Effective doses were rather high (0.9-1.3 mSv for reference-based calculation and 0.15-0.23 mSv for DAP measurement-based calculation) due to the following reasons: 1) the need to cover large imaging areas by a direct beam and under various angles, to visualize important organs, and hence to increase radiation amount to achieve proper photographic density; 2) posterior-anterior plane, usually associated with intensive irradiation of the liver, stomach, esophagus, lungs, as these organs are not shielded by the skeletal system. Effective doses for linear tomography were 5 times higher compared to those for plane chest x-ray.

Age-specific radiation doses for CT were 1.7-2.8 mSv (calculated based on reference doses) and 0.66-1.11 mSv (calculated based on DAP meter readings). Radiation doses for CT were 2 (reference-based effective doses) or 4-5 times higher (DAP meter-derived effective doses), compared to linear tomography.

DAP meter-derived calculation of the effective doses showed age-dose relationship: the highest radiation doses were associated with infancy and adolescence in all imaging methods studied. Likewise, radiosensitivity is known to be dependent on the age: the smaller the age, the higher the radiosensitivity.

Conclusions. Comparison of the results of conventional radiographic examination (chest x-ray and linear tomography) with the results of CT showed that:

- Calculation of diagnostic values confirmed superiority of CT over chest x-ray and linear tomography in diagnosing TB-induced alterations in intrathoracic lymph nodes and lung tissue;
- Radiation exposure during linear tomography and CT is significantly (5 to 25 times) higher than exposure during chest x-ray;
- Linear tomography is irrelevant in the contemporary context, due to its low diagnostic value and high radiation exposure;
- In children and adolescents from risk groups for TB (contact patients, patients with tuberculin skin test conversion, and patients with hyperergic reaction to 2 TU or Diaskintest) CT should be

preferred, and conventional radiographic imaging methods (chest x-ray and linear longitudinal tomography) should be avoided, due to higher diagnostic value of CT.

a.

References:

1. Aksenova V.A. et al. Kliniko-rentgenologicheskaya diagnostika pervichnykh i vtorichnykh form tuberkuleza u detey i podrostkov v sovremennykh usloviyakh: posobie dlya vrachey [Clinical radiographic diagnostics of primary forms of tuberculosis in children and adolescents in contemporary settings: guidebook for physicians]. Moscow; 2003. 45 p. Russian.
2. Gegeeva F.E. Sravnitel'naya kharakteristika rentgenologicheskikh metodov diagnostiki 'malykh' form tuberkuleza vnutrigrudnykh limfaticheskikh uzlov [Comparative characterization of x-ray studies for diagnosing minor forms of tuberculosis of intrathoracic lymph nodes]. Probl Tuberk Bolezn Legk, 2006, no. 1, pp. C. 23-28. Russian.
3. Dovgalyuk I.F., Korneva N.V. Kliniko-epimiologicheskie osobennosti tuberkuleza u detey Severo-Zapada Rossiyskoy Federatsii [The clinical and epidemic features of tuberculosis in children of the northwest areas of the russian federation]. Probl Tuberk Bolezn Legk, 2011, no. 3, pp. 12-16. Russian.
4. Stavitskiy R.V., etal. Dozovye nagruzki na detey pri rentgenologicheskikh issledovaniyakh [Radiation dose in radiographic examination of children]. Moscow: KABUR; 1993. 163 p. Russian.
5. Il'ina N.A. Vozmozhnosti komp'yuternoy tomografii v diagnostike vospalitel'nykh zabolevaniy legkikh u detey [Capacities of computed tomography in diagnosis of inflammatory lung diseases in children]. Synopsis of Cand.Med.Sc.(MD) Thesis. Saint-Petersburg; 2001. 25 p. Russian.
6. Kotlyarov P.M. Luchevye metody v diagnostike zabolevaniy organov dykhaniia [Radiologic methods in the diagnostics of respiratory diseases]. Russkii Meditsinskii Zhurnal, 2001, vol. 1, no. 5, pp. 197-200. Russian.
7. Stavitskiy R.V., ed. Meditsinskaia radiologiia: tekhnicheskie aspekty, klinicheskie materialy, radiatsionnaya bezopasnost' [Medical radiology: technical aspects, clinical material, radiation safety]. Moscow: MNPI; 2003. 343 p. Russian.
8. Ovchinnikova YU.E. et al. Prichiny khronicheskogo techeniia tuberkuleza vnutrigrudnykh limfaticheskikh uzlov u detey, osobennosti klinicheskikh proyavleniy i terapii [Causes of chronic tuberculosis of intrathoracic lymph nodes in children, the specific features of clinical manifestations and therapy]. Tuberk Bolezn Legk, 2010, no. 1, pp. 40-44. Russian.
9. Rozenshtraukh L.S., Rybakova N.I., Viner M.G. Rentgenodiagnostika zabolevaniy organov dykhaniia [Radiographic diagnosis of respiratory diseases], 2nd ed. Moscow: Meditsina; 1987. 640 p. Russian.
10. Smetanin A.G., Dauletanova YA.V. Osobennosti vizualizatsii vnutrigrudnykh limfaticheskikh uzlov pri latentnoy tuberkuleznoy infektsii u detey [Features in the imaging of intrathoracic lymph nodes in pediatric latent tuberculosis infection]. In: Novye tekhnologii v epidemiologii, diagnostike i lechenii tuberkuleza vzroslykh i detey: nauch.-prakt. konf. molodykh uchenykh [New technologies in epidemiology, diagnosis and treatment of tuberculosis in adults and children: young scientists research & practice conference]. Moscow; 2011. p. 62-63. Russian.
11. Stavitskaia N.V., Doroshenkova A.E. Osnovy razrabotki personifitsirovannoy programmy profilaktiki tuberkuleza u detey s latentnoy tuberkuleznoy infektsiey [Bases for elaboration of a personified tuberculosis prevention program in children with latent tuberculosis infection]. Tuberk Bolezn Legk, 2010, no. 8, pp. 37-43. Russian.

12. Stavitskiy R.V., Vikturina V.P. Osnovy radiatsionnoy zashchity v rentgenologicheskoy praktike [Basics of radiation protection in practical radiography]. Moscow: Meditsina; 1968. 108 p. Russian.
13. Stavitskiy R.V. et al. Radiatsionnaya zashchita v meditsinskoy rentgenologii [Radiation protection in medical radiography]. Moscow: Kabur; 1994. 272 p. Russian.
14. Ternovoy S.K., Sinitsyn V.E. Razvitie komp'yuternoy tomografii i progress luchevoy diagnostiki [Progress in computed tomography and radiodiagnosis]. Radiologiia – Praktika, 2005, no. 4, pp. 17-22. Russian.
15. Usol'tsev V.I., Chuykova N.V. Luchevye nagruzki na detey pri rentgenodiagnostike [Radiation exposure in children during radiographic diagnosis]. 1994. 6 p. Saint-Petersburg. Russian.
16. Chikirdin E.K. Rentgenologicheskoe oborudovanie s ponizhennoy dozodoi nagruzkoi [Low radiation dose radiologic equipment]. Vestnik rentgenologii i radiologii, 1994, no. 4, pp. 60-61. Russian.
17. Bosch-Marcet J. et al. Comparison of ultrasound with plain radiography and CT for the detection of mediastinal lymphadenopathy in children with tuberculosis. Pediatr. Radiol., 2004, vol. 34, no. 11, pp. 895-900.
18. Stive F.E. Strahlenschuts in Kindesalter International Empfehlungen zur Frage der trahlenexposition in Kindes und Yugendalter. Radiol. Diagn., 1988, vol. 29, no. 1, pp. 143-155. German.

Authors:

Shepeleva Larisa Petrovna, Head of Department for Radiologic Diagnostics, Phthisiatry Research & Practice Center, Cand.Med.Sc. (PhD in Medicine), address: 677015, Republic Sakha (Yakutia), Yakutsk, ul. Petra Alekseeva, 93, phone: +7(4112)35-03-25, fax: +7(4112)47-50-80, email: shepelevalp@mail.ru

Tyurin Igor' Evgen'evich, Dr.Med.Sc.(MD), Professor, Head of Department for Radiologic Diagnostics, Radiation Therapy and Medical Physics, Russian Medical Academy of Postgraduate Training, Moscow

Kravchenko Alexander Fedorovich, Dr.Med.Sc.(MD), Director, Phthisiatry Research & Practice Center, Yakutsk.

Karymova Lena Emil'evna, internship doctor, Department for Surgical Diseases and Dentistry, Medical Institute, M.K. Ammosov North-Eastern Federal University, Yakutsk.

b.