Evaluation of low-dose CT implementation for lung cancer screening in a general practice hospital

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Abstract. The aim of the current study was to evaluate the possibility of the implementation of LDCT for the screening for lung cancer and tuberculosis in a typical general hospital practice. Diagnostic and economic effectiveness, patient doses and the corresponding radiation risks for LDCT were compared with the existing digital chest screening radiography. The results of the study indicate that the implementation of LDCT allowed verifying false-positive cases or providing additional excessive diagnostic information, but did not significantly improve the sensitivity of screening. Per capita costs for LDCT were higher compared to digital radiography up to a factor of 12; corresponding radiation risk – by a factor of 4. Hence, it was considered unjustified to implement LDCT in a general practice hospital.

1. Introduction
Lung cancer is the second leading cause of death in the Russian Federation after blood circulatory system diseases, corresponding to about 10 % in the structure of the primary malignant cancer incidence. Lung cancer corresponds to 28 % and 7 % in the structure of the cancer mortality for males and females, respectively. One of the reasons for that is the ineffective diagnostic of lung cancer on early stages [1]. The detection of lung cancer is of paramount importance in mortality reduction. Recent developments in computed tomography (CT) allow using low-dose CT (LDCT) for the lung cancer screening. LDCT protocols use lower tube voltage and tube current as well as higher slice thickness, compared to standard chest CT protocols. That allows keeping the typical effective dose per LDCT examination in a range of 1 mSv, preserving the acceptable diagnostic image quality for the lung nodules detection. Clinical trials in different countries indicated a significant increase in the number of the early lung cancers detected with LDCT compared to the conventional chest screening methods [2–4]. These trials were focused on different risk groups, commonly considering the age (50–80 years) and the smoking experience (20+ pack-years) [5].
However, chest screening in the Russian Federation is mainly focused on the detection of tuberculosis, professional and inflammatory diseases of the chest. It is performed using conventional chest radiography on the dedicated digital or film-based X-ray units (film-based and digital fluorography). Almost all the working Russian population undergoes annual conventional X-ray screening on an outpatient basis. Since 2014, there is an ongoing discussion on the implementation of LDCT in the screening programs, but the number of studies and trials is limited.

Hence, the aim of the current study was to evaluate the possibilities of the implementation of LDCT for the lung cancer screening in a typical general practice hospital in Russia. Diagnostic and economic effectiveness, patient doses and the corresponding radiation risks for LDCT were compared with the existing digital chest screening radiography.

2. Materials and methods

The study was performed in the X-ray and CT departments in a general practice St. Petersburg “Urban Mariinsky hospital” in 2016–17. The study consisted of two parts: retrospective and prospective. A retrospective part was focused on the analysis of the sample of 8554 patients that underwent a conventional digital X-ray chest screening in 2016. The following parameters were considered: age and gender of the patient; parameters of the chest X-ray examination, relevant for the estimation of the effective dose and the diagnostic conclusion of the radiologists. Data was obtained from the patient medical cards and DICOM archives with subsequent anonymization.

Prior to the study, criteria for the selection of the patients corresponding to the risk groups were developed based on the data from the foreign trials. Criteria included age of 40+ years and smoking experience of 20+ pack-years. Patients corresponding to the criteria were selected from the patient flow and invited to participate in the study with the signed patient informed consent. A total of 126 patients agreed to participate in the prospective study. They were divided into two sample based on the result of the conventional X-ray chest screening: 103 patients without pathologies and 23 patients with any identified pathology. 10 random patients from a sample without pathologies and all patients with pathologies were referred to LDCT (a total of 33 patients) with a subsequent chest CT. The design of the study was approved by the local ethical committee.

Conventional chest X-ray screening was performed on a digital X-ray unit FC-01 (ZAO “NIPK “ELECTRON”, Russia) with a CCD-matrix detector, using standard chest protocol: tube voltage 100 kV, focal image distance 150 cm, field size of 35×35 cm, total filtration thickness of 5 mm Al, with grid and automatic exposure control. LDCT and CT were performed on a Somatom Definition 64 (Siemens, Germany) unit. Data on the chest LDCT and CT protocols is presented in Table 1.

| Protocol | Tube voltage, kV | Tube current, mA | Pitch | Collimation | Slice thickness, mm |
|----------|------------------|------------------|-------|-------------|--------------------|
| LDCT     | 100              | 40               | 1.35  | 64×0.6      | 5.0                |
| CT       | 120              | 80–200<sup>1</sup> | 1.35  | 64×0.6      | 1.0                |

<sup>1</sup> with automatic mA modulation

Conventional chest X-ray images were read by the radiologist with 4 years of experience; LDCT and CT images – by the head of the CT department with 10 years of experience.

Effective doses for the conventional chest X-ray screening were estimated using PCXMC 2.0 software (STUK, Finland) based on tissue weighting coefficients from ICRP Publication 60; effective doses for the CT examinations were estimated using conversion coefficients from the existing Russian guidelines [6]. Radiation risks were estimated according to the guidelines [7].

Diagnostic effectiveness of the conventional chest X-ray screening and LDCT was evaluated based on the comparison of sensitivity, specificity, negative and positive predictive values. Economic effectiveness was evaluated based on the comparison of the per patient expenses during a 10-year period (minimal lifespan for the X-ray equipment before the replacement). The following factors were
considered: staff yearly salary; price of the new equipment; technical maintenance and service expenses. The prices are provided in Russian rubles (RUR); prices are valid for 2017.

3. Results
The results of the retrospective analysis of the patient data are presented in tables 2 and 3.

Table 2. Distribution of the conclusions for the 2016 patient sample.

| Result                                     | Number of patients | %  |
|--------------------------------------------|--------------------|----|
| No pathology                               | 7339               | 85.79 |
| Infiltrate                                  | 256                | 2.99 |
| Consolidation                               | 65                 | 0.76 |
| Single pulmonary nodule                     | 39                 | 0.46 |
| Posttuberculosis calcificate                | 102                | 1.19 |
| Disseminated processes                      | 17                 | 0.20 |
| Tuberculosis                                | 16                 | 0.19 |
| Malignant lesion (lung cancer/metastases)   | 21                 | 0.24 |
| Other                                       | 699                | 8.17 |

Table 3. Age distribution for the 2016 patient sample.

| Age group | Number of patients | %   |
|-----------|--------------------|-----|
| 15–25     | 939                | 10.9|
| 26–35     | 1811               | 21.2|
| 36–45     | 1410               | 16.5|
| 46–55     | 1390               | 16.2|
| 56–65     | 1433               | 16.8|
| 66–75     | 864                | 10.1|
| 76–85     | 579                | 6.8 |
| 86–95     | 124                | 1.4 |
| 96+       | 4                  | 0.1 |

Comparison of the patient doses from conventional chest X-ray screening, LDCT and chest CT is presented in table 4. Data is presented as mean ± SD (min–max).

Table 4. Comparison of the patient doses for the 2017 patient sample.

| Examination         | Dose-area product, μGy·m² | DLP, mGy·cm | Effective dose, mSv |
|---------------------|---------------------------|-------------|---------------------|
| Conventional chest X-ray | 71.4 ± 31.8¹ (37.4–157.2) | –           | 0.13 ± 0.06 (0.06–0.28) |
| LDCT                | –                         | 56.7 ± 5.3 (49.6–68) | 0.96 ± 0.09 (0.84–1.16) |
| Chest CT            | –                         | 283.6 ± 26.3 (248–340) | 4.82 ± 0.45 (4.22–5.78) |

Comparison of the diagnostic effectiveness between the conventional chest X-ray screening and LDCT is presented in table 5.

Table 5. Comparison of the diagnostic effectiveness between the conventional chest X-ray screening and LDCT for the 2017 patient sample.

|                      | Sensitivity, % | Specificity, % | Positive predictive value, % | Negative predictive value, % | Diagnostic effectiveness, % |
|----------------------|---------------|---------------|-------------------------------|-------------------------------|------------------------------|
| Conventional chest X-ray | 93           | 47           | 57                           | 90                           | 67                           |
| LDCT                 | 93           | 100          | 100                          | 95                           | 97                           |
Comparison of the corresponding radiation risks for the conventional X-ray chest screening and LDCT is presented in table 6. Patient age distributions are taken from table 3; effective dose values – from table 4.

**Table 6. Comparison of the radiation risks between the conventional chest X-ray screening and LDCT.**

| Examination                  | Age group | Number of patients | Age-specific coefficient | Total effective dose | Collective risk | Lifetime attributable risk |
|------------------------------|-----------|--------------------|--------------------------|----------------------|-----------------|---------------------------|
| Conventional chest X-ray     | <18       | 52                 | 2.3                      | 7.73                 | 0.001           | 0.099                     |
|                              | 18–65     | 6923               | 0.9                      | 1840.27              | 0.094           | 0.355                     |
|                              | 65+       | 1423               | 0.1                      | 645.17               | 0.004           |                           |
|                              | <18       | 52                 | 2.3                      | 49.92                | 0.007           |                           |
| LDCT                         | 18–65     | 6923               | 0.9                      | 6646.08              | 0.341           | 0.355                     |
|                              | 65+       | 1423               | 0.1                      | 1366.08              | 0.008           |                           |

Comparison of the expenses per patient for the conventional chest X-ray screening and LDCT for the 10-year period is presented in table 7. Data is presented in RUR. Prices are valid for 2017.

**Table 7. Structure of expenses for the conventional chest X-ray screening and LDCT.**

| Expenses                                           | Conventional chest X-ray, RUR | LDCT, RUR   |
|----------------------------------------------------|-------------------------------|-------------|
| Staff salary                                       | 4800000                       | 4800000     |
| Maintenance                                        |                               |             |
| Costs for the new X-ray/CT unit                     | 5203175                       | 51220000    |
| Yearly technical maintenance                       | 350000                        | 2000000     |
| X-ray tube replacement                              | –                             | 5200000     |
| Maximum number of patients per day                  | 34                            | 25          |
| Number of patients for the 10-year period           | 850000                        | 61750       |
| Total expenses for the X-ray unit/CT for the 10-year period | 13503175                      | 120908000   |
| Expenses per 1 patient                             | 159                           | 1958        |

**4. Discussion**

As it is visible from table 2, more than 85% of the patients had no identified pathology according to the conclusion. The number of malignant lesions was low – only 21 cases, corresponding to 0.24%. It can be explained by low malignant morbidity for the patient sample or by low detectability of the malignant lesions using conventional methods (digital radiography). It should be noted that age distribution for the patient sample is shifted towards age 40+ and is comparable with the patient samples used in other LDCT screening trials. Unfortunately, no data on smoking experience was available for the 2016 patient sample.

Comparison of the diagnostic effectiveness between the conventional chest X-ray screening and LDCT was performed based on the chest CT evaluation and conclusions. According to table 5, both modalities had identical sensitivity. However, the specificity and positive predictive value of the conventional chest X-ray screening were lower by a factor of 2; resulting diagnostic effectiveness – by a factor of 1.5. High sensitivity of conventional chest X-ray screening justifies its use as a screening tool – the ability to detect the pathology, with the subsequent CT or LDCT verification of the findings. According to the analysis of the radiologists' conclusions, LDCT results did not differ significantly
from the conventional chest X-ray screening, providing additional or excessive information. It should be noted that the current study was performed on a limited scale due to the high patient flow in a CT department. That could definitely influence the results. For instance, there was only one case of lung cancer identified in 2017 patient sample (later verified by the biopsy). Nevertheless, the design of the study can be used later on a larger scale.

According to the data from table 6, the replacement of conventional X-ray screening by the LDCT would lead to an increase in the number of radiation-induced cancers by a factor of 4: from 1.05 cases to 4.2 cases per 100 000 patients in addition to the background cancer incidence. However, that increase is negligible in comparison with data from table 2 (246 cases of malignant lesions recalculated per 100 000 patients).

The results of comparison of economic efficiency indicate significant differences between the conventional X-ray screening and LDCT: overall expenses per patients differ by a factor of 12. Technical maintenance costs for a CT unit exceed the costs for an X-ray unit by a factor of 6, which is significant in the current Russian clinical environment. It should be noted that the another limiting factor for the implementation of the LDCT screening is the capacity of the CT-unit (number of patients per day in less compared with the X-ray unit by a factor of 1.5). The implementation of LDCT screening would lead to the installation of an additional (or several, to maintain the patient flow) CT-unit; conventional chest X-ray screening can be performed on virtually any X-ray unit. The economic factors are the main limiting factors for the implementation of LDCT for lung cancer screening as all the screening examinations are funded by the Ministry of Healthcare.

5. Conclusions
The results of the current study indicate the lack of significant differences between conventional chest X-ray screening and LDCT in terms of sensitivity, justifying the use the existing chest screening method. LDCT allowed verifying false-positive cases and acquiring additional diagnostic information. The increase in the patient effective doses and the corresponding radiation risk for LDCT was not considered to be significant. However, a significant disadvantage of LDCT as a screening tool is associated with expenses per patient and limited availability of the CT-units. Hence, the use of LDCT as a screening tool in a general practice hospital is unjustified.

References
[1] Venkatesh A, Mannudeep K, et al. 2015 J. Thorac. Imaging 30 283–9
[2] Infante M, Cavuto S, Lutman F R, et al. 2009 Am J Respir Crit Care Med 180 445–53
[3] Pastorino U, Rossi M, Rosato V, et al. 2012 Eur J Cancer Prev 21 308–15
[4] Aberle D R, Adams A M, Berg C D, et al. 2013 N Engl J Med 368 1980–91
[5] Kanodra N M, Silvestri G A and Tanner N T 2015 Cancer 1 1347–56
[6] Assessment of effective dose to the patients undergoing X-ray examinations. Methodical guidance 2.6.1.2944-11 (Moscow: Rospotrebnadzor)
[7] Assessment of radiation risks of patients undergoing diagnostic examinations with the use of ionizing radiation. Methodical recommendations 2.6.1.0098-15 (Moscow: Rospotrebnadzor)