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Вклад систем искусственного интеллекта в улучшение выявления аневризм аорты по данным компьютерной томографии грудной клетки

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АННОТАЦИЯ

Обоснование. Аневризмы аорты — «тихие убийцы», развиваются без симптомов и могут привести к летальному исходу. Ежегодно заболеваемость аневризмой грудной аорты составляет около 10 случаев на 100 000 человек, а частота разрывов аневризмы — около 1,6 случая. Ранняя диагностика и лечение могут спасти жизнь пациента. Использование технологий искусственного интеллекта может значительно улучшить качество диагностики и предотвратить летальный исход.

Цель — оценить эффективность применения технологий искусственного интеллекта в выявлении аневризм грудного отдела аорты на компьютерной томографии органов грудной клетки и исследовать возможности использования этих технологий в качестве системы поддержки принятия врачебных решений врача-рентгенолога при первичном описании лучевых исследований.

Материалы и методы. Были оценены результаты использования технологий искусственного интеллекта для выявления аневризмы грудной аорты на компьютерной томографии органов грудной клетки без контрастного усиления. Была сформирована выборка из 84 405 случаев обследования пациентов старше 18 лет, из которых отобрано и ретроспективно пересмотрено сосудистыми хирургами Научно-исследовательского института скорой помощи имени Н.В. Склифосовского 86 исследований с подозрением на наличие аневризмы грудного отдела аорты по данным технологий искусственного интеллекта. Эти исследования были также ретроспективно оценены двумя врачами-рентгенологами.
Была сформирована дополнительная выборка из 968 исследований, взятых в случайном порядке из общего числа, для оценки корреляции возраста пациентов и диаметра грудного отдела аорты.

Результаты. Анализ показал, что в 44 исследованиях аневризма была первично выявлена врачом-рентгенологом, в 31 случае аневризмы не были описаны, но технология искусственного интеллекта помогла выявить патологию. Ещё 6 исследований были исключены из выборки, а в 5 случаях были обнаружены ложноположительные результаты анализа. Использование технологий искусственного интеллекта обнаруживает и выделяет патологические изменения аорты на медицинских изображениях, тем самым повышая выявляемость аневризмы грудной аорты при интерпретации результатов компьютерной томографии органов грудной клетки на 41%. При первичном описании лучевых исследований и в ретроспективных исследованиях целесообразно использовать технологии искусственного интеллекта для профилактики пропусков клинически значимых патологий — как в качестве системы поддержки принятия врачебных решений для врача-рентгенолога, так и для повышения выявляемости патологического расширения грудного отдела аорты.
По дополнительной выборке в популяции взрослого населения частота дилатации грудного отдела аорты составила 14,5%, а аневризм грудного отдела аорты —1,2%. Данные также показали возрастную зависимость диаметра грудного отдела аорты для мужчин и женщин.

Заключение. Применение технологий искусственного интеллекта в процессе первичного описания результатов компьютерной томографии органов грудной клетки может повысить выявляемость клинически значимых патологических состояний, таких как аневризма грудного отдела аорты. Расширение ретроспективного скрининга по данным компьютерной томографии органов грудной клетки с использованием технологий искусственного интеллекта может улучшить качество диагностики сопутствующих патологий и предотвратить негативные последствия для пациентов.

Ключевые слова: компьютерная томография; аневризма аорты; искусственный интеллект.

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Improving aortic aneurysm detection with artificial intelligence based on chest computed tomography data

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ABSTRACT

BACKGROUND: Aortic aneurysms are known as "silent killers" because this potentially fatal condition can be asymptomatic. The annual incidence of thoracic aortic aneurysms and ruptures is approximately 10 and 1.6 per 100,000 individuals, respectively. The mortality rate for ruptured aneurysms ranges from 94% to 100%. Early diagnosis and treatment can be life-saving. Artificial intelligence technologies can significantly improve diagnostic accuracy and save the lives of patients with thoracic aortic aneurysms.

AIM: This study aimed to assess the efficacy of artificial intelligence technologies for detecting thoracic aortic aneurysms on chest computed tomography scans, as well as the possibility of using artificial intelligence as a clinical decision support system for radiologists during the primary interpretation of radiological images.

MATERIALS AND METHODS: The results of using artificial intelligence technologies for detecting thoracic aortic aneurysms on non-contrast chest computed tomography scans were evaluated. A sample of 84,405 patients >18 years old was generated, with 86 cases of suspected thoracic aortic aneurysms based on artificial intelligence data selected and retrospectively assessed by radiologists and vascular surgeons. To assess the age distribution of the aortic diameter, an additional sample of 968 cases was randomly selected from the total number.

RESULTS: In 44 cases, aneurysms were initially identified by radiologists, whereas in 31 cases, aneurysms were not detected initially; however, artificial intelligence aided in their detection. Six studies were excluded, and five studies had false-positive results. Artificial intelligence aids in detecting and highlighting aortic pathological changes in medical images, increasing the detection rate of thoracic aortic aneurysms by 41% when interpreting chest computed tomography scans. The use of artificial intelligence technologies for primary interpretations of radiological studies and retrospective assessments is advisable to prevent underdiagnosis of clinically significant pathologies and improve the detection rate of pathological aortic enlargement. In the additional sample, the incidence of thoracic aortic dilation and thoracic aortic aneurysms in adults was 14.5% and 1.2%, respectively. The findings also revealed an age-dependent diameter of the thoracic aorta in both men and women.

CONCLUSION: The use of artificial intelligence technologies in the primary interpretation of chest computed tomography scans can improve the detection rate of clinically significant pathologies such as thoracic aortic aneurysms. Expanding retrospective screening based on chest computed tomography scans using artificial intelligence can improve the diagnosis of concomitant pathologies and prevent negative consequences.

Keywords: computed tomography; aortic aneurysm; artificial intelligence.

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人工智能系统对从胸部计算机断层扫描数据中改进主动脉瘤检测的贡献

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摘要

论证。主动脉瘤是“无声杀手”，发病时没有任何症状，而且可能致命。胸主动脉瘤的年发病率约为每10万人10例，动脉瘤破裂的发病率约为1.6例。早期诊断和治疗可以挽救患者的生命。人工智能技术的使用可以大大提高诊断质量，防止死亡。

目的。本研究的目的是评估人工智能技术在胸部计算机断层扫描中检测胸主动脉瘤的有效性，并探讨这些技术作为放射科医生临床决策支持系统在放射学检查初步描述中的可行性。

材料与方法。对使用人工智能技术在无对比度增强的胸部计算机断层扫描中检测胸主动脉瘤的结果进行了评估。研究人员对84405名18岁以上的患者进行了抽样检查。通过人工智能技术筛选出86个疑似胸主动脉瘤的检查。俄罗斯N.V.斯克利福索夫斯基急救研究所的血管外科医生对这些检查结果进行了回顾性分析。两名放射科医生也对这些检查进行了回顾性评估。另外从总数中随机抽取，形成了包括968个检查在内的额外样本以评估患者年龄与胸主动脉直径之间的相关性。

结果。分析表明，在44例检查中，动脉瘤最初是由放射科医生检测到的；在31例检查中，动脉瘤未被描述，但人工智能技术帮助确定了病理。另有6例检查被排除在样本之外，而有5例检查发现了假阳性检测结果。

使用人工智能技术可以检测并突出显示医学图像中主动脉的病理变化。因此，在解读胸部计算机断层扫描结果时发现胸主动脉瘤的概率提高了41%。在放射学研究的初步描述和回顾性研究中，使用人工智能技术来防止遗漏具有临床意义的病理是可行的，既可作为放射科医生的医疗决策支持系统，又可提高胸主动脉病理扩张的可探测性。

在另一个成年人群样本中，胸主动脉扩张的发生率为14.5%，胸主动脉瘤的发生率为1.2%。数据还显示了，男性和女性的胸主动脉直径与年龄有关。

结论。将人工智能技术应用于胸部器官CT结果的初步描述过程中，可以提高对胸主动脉瘤等临床重大病理状态的检测。利用人工智能技术扩大胸部计算机断层扫描的回顾性筛查范围，可提高合并症的诊断质量，避免给患者带来不良后果。

关键词：电子计算机断层扫描；主动脉瘤；人工智能。

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BACKGROUND

According to the World Health Organization, cardiovascular diseases and associated disorders are among the leading causes of death [1]. These diseases include aortic aneurysms, which are known as “silent killers.” They are generally asymptomatic and can result in aortic dissection or rupture, which leads to death in 94%–100% of cases [2, 3]. Very few studies have statistically analyzed the prevalence of thoracic aortic aneurysms [4]. In Russia, the incidence of ascending aortic aneurysms ranges from 0.16% to 1.06%. Notably, a recent large epidemiological study on the incidence of thoracic aortic aneurysms in Russia was performed approximately 40 years ago [5], highlighting the need for further studies.

According to autopsy data collected over 10 years in the Filatov City Clinical Hospital No. 15 (Moscow), a thoracic aortic aneurysm was the cause of death in 0.8% of cases, with aneurysms suspected before death in only 11% of these cases [4]. In the USA, aortic aneurysms are the 17th leading cause of cardiovascular-related death, with an annual prevalence of thoracic aortic aneurysms of approximately 10 per 100,000 of population and an aneurysm rupture prevalence of approximately 1.6 per 100,000 of population [6]. In Sweden, thoracic aneurysms and aortic dissections occur in up to 16.3 per 100,000 of population [7]. According to Yale University data, the annual incidence rates of aneurysm ruptures and aortic dissections are 3.6% and 3.7% of the reported cases, respectively [8].

During screening for lung tumors using chest computed tomography (CT), abnormal thoracic aortic dilatation is detected in up to 8.1% of patients aged >50 years [9, 10].

Opportunistic screening is a prospective and retrospective analysis of relevant cases to identify conditions and risk factors in addition to the target pathology. This strategy eliminates the need for repeated examinations, reducing the patient’s radiation exposure [11].

In 2022, more than 647,000 noncontrasted chest CT studies were performed in Moscow. This number of examinations allows for the opportunistic detection of various pathological conditions, including life-threatening ones such as thoracic aortic dilatation (aneurysm) [12].

Since 2020, the world’s largest study has been conducted in Moscow to assess the efficacy and quality of artificial intelligence (AI) technology: “An experiment on the use of innovative computer vision technologies for the analysis of medical images and further use in the healthcare system of the city of Moscow” (Moscow Experiment) [13]. AI technology is used in the test mode in the Moscow Experiment, under the supervision of experts of the Center for Diagnostics and Telemedicine (Moscow). The process includes a continuous quality assessment of the system and adjustments to its operation, calculations of accuracy metrics, and identification of operation errors and other characteristics. Consequently , conditions are created for performing retrospective studies and processing X-ray findings during the primary analysis by a radiologist.

AIM

To assess the efficacy of AI technology in detecting thoracic aortic aneurysms based on chest CT findings and investigate the possibility of using AI technology as a medical decision support system for radiologists during the primary assessment of X-ray findings.

MATERIALS AND METHODS

Study design

A retrospective analysis of 84,405 chest CT scans was performed. Data were derived from the Unified Radiology Information Service of the automated Unified Medical Information Analysis System (ERIS EMIAS) of Moscow between June 1, 2022, and November 30, 2022, and processed using AI technology. The study design is presented in Fig. 1. The total sample included 84,405 patients aged >18 years, from which 86 examinations with a suspected thoracic aortic aneurysm with a maximum diameter of >50 mm were selected using AI technology data. The examinations were selected by vascular surgeons of the Sklifosovsky Institute for Emergency Medicine.

The resulting sample was then reviewed by two radiologists from the Center for Diagnostics and Telemedicine with over 5 years of experience. If the first two radiologists disagreed, an expert with 10 years of experience in radiology acted as an arbitrator and made the final decision on the presence of an aneurysm and its description.

During the review, eleven patients were excluded, specifically because the radiologist did not provide a primary protocol in the ERIS in six patients and the results were classified as false positive after AI data processing (assessment of a nontarget pathology or organ) in five patients. The resulting sample included 75 patients referred for a follow-up examination and treatment.

In addition, 1,000 scans were randomly selected from the total sample of 84,405 examinations to assess the distribution of aortic diameter vs. age. After the exclusion of 32 patients due to missing data on patients’ ages, the resulting sample included 968 patients (433 males and 535 females, 44.7% and 55.3%, respectively).

Inclusion criteria

The inclusion criteria for chest CT scans in the sample for analysis using AI technology during the Moscow Experiment in the Thoracic Aortic Aneurysm area were as follows:

- Outpatients and inpatients (male and female patients) of the institutions forming part of the Moscow Healthcare Department (aged >18 years)
- Examination type: noncontrasted chest CT with ⩽3 mm slice thickness
- Availability of chest CT scans in the DICOM format and the radiologist’s protocol in the ERIS EMIAS

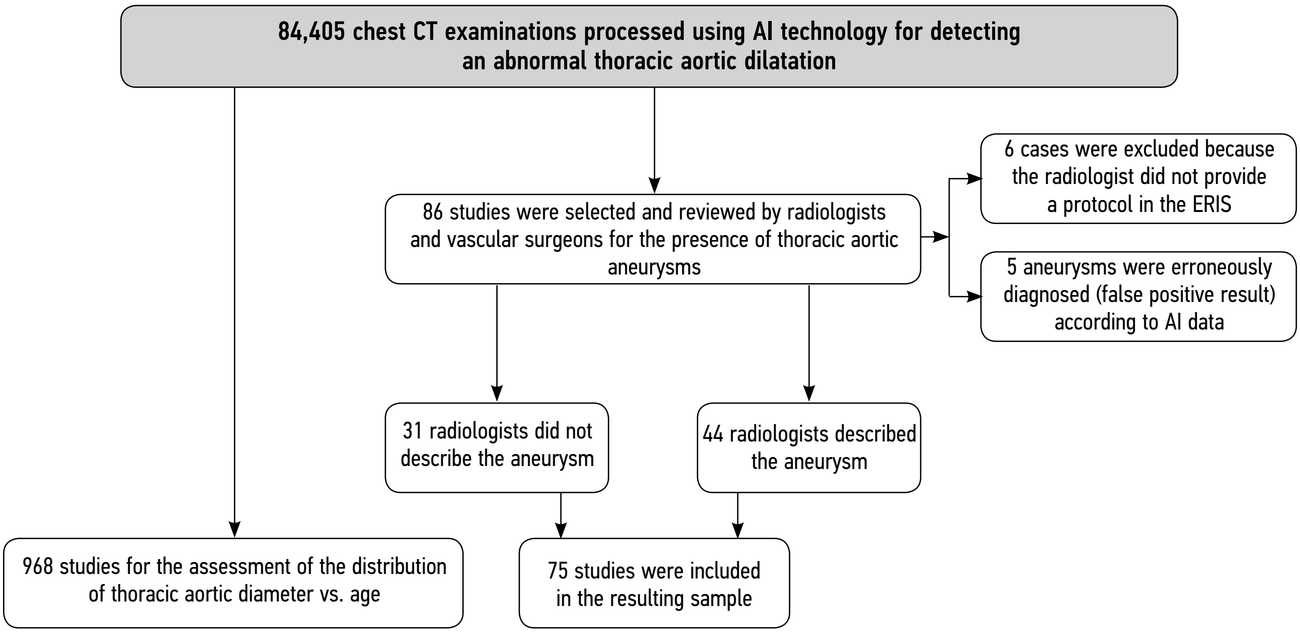

Fig. 1. Study design. AI, artificial intelligence, CT, computed tomography; ERIS, Unified Radiology Information Service.

The exclusion criteria were as follows:

- Patients with surgical hardware (postoperative clamps or plates) creating artifacts in the chest area, including pacemakers
- Contrast enhancement and lung kernel CT
- Absence of chest CT scans in the DICOM format and/or the radiologist's protocol in the ERIS EMIAS.

Study conditions

According to the basic diagnostic requirements, AI technology was used to process examination findings for detecting abnormal thoracic aortic dilatation. These requirements were developed based on the European Society of Cardiology guidelines on the diagnosis and treatment of aortic diseases [14]:

- Ascending aortic dilatation: 40–49 mm
- Ascending aortic aneurysm: ⩾50 mm
- Descending aortic aneurysm: ⩾40 mm [15]

The domestic AI algorithm Chest-IRA (IRA Labs, Russia) was used to automatically determine the thoracic aortic diameter. The accuracy of this AI technology was assessed during the Moscow Experiment, with the following results:

- Area under the ROC curve (AUC): 0.99
- Sensitivity: 0.94
- Specificity: 0.96
- Accuracy: 0.95
- Duration of analysis (one examination): 2.1 min [16]

An example of an AI technology algorithm operation is presented in Fig. 2.

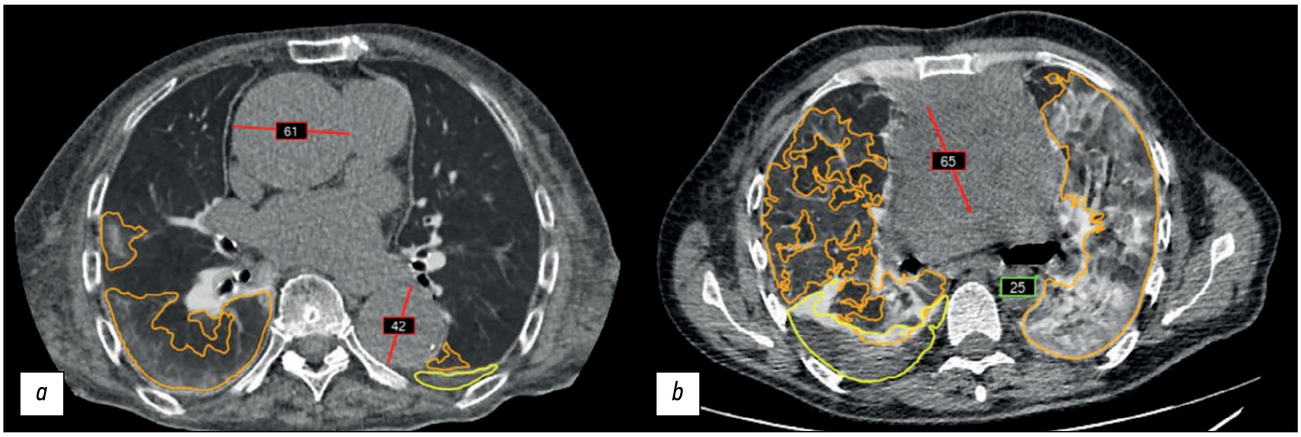

Fig. 2. An example of an algorithm operation of a complex AI-based service to process chest CT findings: *a*: AI technology correctly selected and marked (red line) the suspected ascending and descending thoracic aortic aneurysms; *b*: a false positive result: a mediastinal neoplasm was marked (red line) together with the ascending thoracic aorta; the green frame indicates the diameter of the descending thoracic aorta. This complex AI-based service has additional modules for marking pulmonary infiltrates (orange outline) and pleural effusion (yellow outline).

The retrospective verification of CT scans with suspected thoracic aortic aneurysms in the total sample of 75 studies (maximum diameter: >50 mm) was performed by two radiologists (with >5 years of experience), one expert radiologist, and vascular surgeons (with >10 years of experience). The correctness of AI technology operation in measuring the thoracic aorta in the axial plane was assessed. According to the guidelines of the European Association of Cardiovascular Imaging and the European Society of Cardiology, the physicians measured both the maximum anteroposterior diameter and the perpendicular diameter of the thoracic aorta [17]. All patients in the sample were referred for a follow-up examination to decide on further monitoring or treatment.

The normality of distribution in the groups of patients was assessed using the Shapiro–Wilk test. Given that the distribution was not normal (p <0.001), all subsample values are presented as median [25th percentile; 75th percentile] and minimum/maximum. Between-group comparisons were performed by the Mann–Whitney method.

RESULTS

Primary study results

The AI technology algorithm was used to process 84,405 noncontrasted chest CT scans for detecting abnormal thoracic aortic dilatation. In total, 86 patients (62 male and 24 female patients) with a suspected thoracic aortic aneurysm according to AI technology findings were selected from this sample and retrospectively reviewed by radiologists and vascular surgeons. Of 86 patients, six were excluded from the sample because no protocol was available in the ERIS, and five had a false positive result after AI data processing (assessment of a nontarget pathology or organ, Fig. 2, *b*); these five patients were also excluded from the sample.

The resulting sample included 75 patients: 57 male (66 [59; 73]; 27–87 years) and 18 female patients (62 [59; 74]; 47–87 years). Thoracic aortic aneurysms were described in the primary X-ray protocol in 44 (59%) cases; in 31 (41%) cases, aneurysms were not mentioned in the primary protocol. Thus, AI technology allowed for detecting 31 additional cases of thoracic aortic aneurysms (41%). In this group, the maximum thoracic aortic diameter was 56 [54; 60]: 52–84 mm in male and 57 [54; 63]; 52–87 mm in female patients.

Patients with aortic aneurysms detected using AI technology on chest CT scans were informed and referred for follow-up examinations (echocardiography, CT, or magnetic resonance angiography, and cardiologist or vascular surgeon consultation) to determine the management and treatment strategy.

The follow-up examinations provided additional information: 4 (5.33%) of 75 patients died before the end of diagnostic procedures or surgery, and 3 (4%) patients refused follow-up examinations and treatment. Another 31 (41.33%) patients were lost to follow-up.

In 25 (33.33%) of 37 patients who remained under follow-up and continued treatment, thoracic aortic aneurysm was confirmed (ongoing follow-up); in 12 (16%) patients, the diagnosis was clarified (still being treated by a cardiologist). In 3 patients, the diagnosis of aneurysm was not confirmed after a diagnostic examination; these patients were diagnosed with thoracic aortic dilatation. Moreover, two surgeries (aortic stenting) were performed for aneurysms.

No significant differences in age and thoracic aortic diameter were found between the groups of male and female patients with aneurysms detected using AI technology (p>0.05).

Findings of the second part of the study

Preliminary data on the incidence of aneurysms was obtained in the sample including 968 cases (Fig. 3) randomly

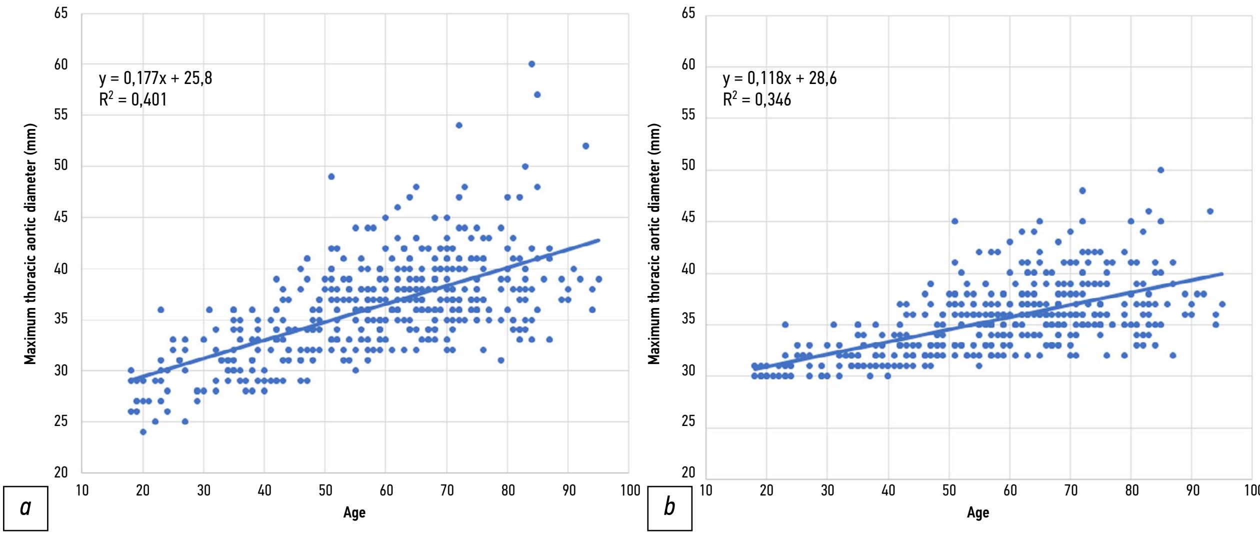

Fig. 3. Plot of the maximum thoracic aortic diameter versus age for the sample including 968 examinations: *a*: male patients; *b*: female patients.

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selected from 84,405 cases. In the adult population (aged ⩾18 years), the incidence rates of thoracic aortic dilatation and aneurysms were 14.5% and 1.2%, respectively.

The female patients were 65 [51; 75]; 19–102 years old (n = 535), and the male patients were 60 [47; 71]; 18–95 years old (n = 433). There were slightly more female patients than male patients, reflecting the sex distribution in the total patient population studied. The median age of the female patients (65 years) was slightly higher than that of male patients (60 years), and the interquartile ranges were comparable.

In this group, the thoracic aortic diameter was 34 [31; 37]; 20–50 mm in female patients and 36 [33; 39]; 24–60 mm in male patients.

Significant (p<0.001) differences in age and maximum thoracic aortic diameter were found between the male and female patients. A pronounced association of the thoracic aortic diameter and age was found in male and female patients. In male patients, relative age-related changes in the thoracic aortic diameter are more pronounced at 0.177 mm/year; in female patients, this parameter was 0.118 mm/year.

DISCUSSION

Result summary

The analysis showed no significant differences (p >0.05) in age or maximum thoracic aortic diameter between male and female patients with aortic aneurysms (n = 75). In the sample including 968 patients (randomly selected from the total sample), significant differences (p<0.001) in age and maximum thoracic aortic diameter were found between male and female patients. This highlights the need for age and sex standards to describe the distribution by age. In addition, well-designed studies are necessary for a more comprehensive analysis of the observed trends.

Discussion of study findings

An increase in the detection rate of aneurysms in a retrospective study employing an AI algorithm confirms the efficacy and feasibility of this approach in clinical practice, e.g., as an accessory tool for radiologists during the primary assessment of X-ray findings. However, the software also provided some false positive results. Methods to minimize such errors by monitoring and fine-tuning the algorithm have been reported [20–22].

According to the literature, a positive correlation existed between age and thoracic aortic diameter. Men generally have larger thoracic aortic diameters than women [18], as well as a more pronounced association between age and thoracic aortic diameter [19], which is consistent with the statistical analysis findings in this study.

Physicians are at risk of missing clinically significant conditions for various reasons, including professional burnout (e.g., following the COVID-19 pandemic), increasing workload, and medical personnel shortage. This is another argument in favor of using AI technology as a medical decision support system for radiologists when assessing chest CT scans. AI technology can improve the detection rate and reduce the number of missed clinically significant pathologies [23].

The domestic AI technology used in this study is not the only one in the world, and quality metrics can be used when selecting AI algorithms. Foreign analogs of AI technology are also available for automatic measurement of the thoracic aortic diameter and detection of aneurysms; these solutions allow avoiding errors and can be used in opportunistic screening [24, 25].

According to the literature, AI technology helps radiologists reduce the time spent on detecting pathologies in X-ray images [26, 27].

AI-based solutions are a promising tool for aortic measurements [28]. However, the accuracy of these measurements must be confirmed by further research. This study demonstrates that although AI cannot replace physicians, it can aid radiologists by warning them of potential aortic pathologies, allowing them to avoid missing clinically relevant abnormalities. Radiologists must understand the principle of AI technology operation and possible errors when analyzing study findings [29–33]. Thus, the use of AI in medicine can be a valuable tool in detecting thoracic aortic aneurysms. Accordingly, AI technology must be used to detect abnormal thoracic aortic dilatation during the primary assessment of X-ray findings and in retrospective analysis to reduce the risk of missing clinically significant changes.

CONCLUSIONS

The use of AI technology during the primary assessment of chest CT images and for expanded opportunistic screening may improve the diagnosis of clinically significant pathologies, such as thoracic aortic aneurysms, and prevent unfavorable outcomes. Further optimization of the routing in this patient population requiring urgent medical intervention for timely surgical treatment is crucial. Thus, population reference values for thoracic aortic diameter must be established to adjust the diagnostic criteria for this condition.

ADDITIONAL INFORMATION

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