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Contents

Integrative Radiological and Neuropsychiatric Evaluation in Tuberous Sclerosis Complex: Bridging Imaging Findings to Behavioral Outcomes

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ABSTRACT

Tuberous Sclerosis Complex (TSC) is a rare autosomal dominant genetic disorder characterized by the formation of benign tumors in multiple organs, including the brain, kidneys, heart, lungs, and skin. Mutations in TSC1 or TSC2 genes, encoding hamartin and tuberin, respectively, disrupt cell growth regulation and result in uncontrolled proliferation. Renal angiomyolipomas (AMLs), a frequent complication of TSC, pose a significant risk for hemorrhage and renal dysfunction. Other clinical manifestations include neuropsychiatric features such as epilepsy, intellectual disability, autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), and mood disorders, which can profoundly affect cognitive, behavioral, and social domains.

Radiological imaging plays a crucial role in the diagnosis and management of TSC, allowing for the early detection of hallmark features such as cortical tubers, subependymal nodules, and radial migration lines. Advanced modalities like magnetic resonance imaging (MRI) not only enhance visualization of these structural abnormalities but also help establish their connection to neuropsychiatric outcomes and are essential for guiding personalized treatment approaches. When combined with behavioral assessment tools, such as the Strengths and Difficulties Questionnaire (SDQ) and the TAND Checklist, imaging contributes to a more comprehensive understanding of TSC, supporting accurate diagnosis, targeted interventions, and holistic patient care.

This scientific paper underscores the importance of early detection, radiological expertise, and multidisciplinary care in mitigating the complex challenges posed by TSC. By bridging neuroimaging findings with clinical and neuropsychiatric implications, this research aims to enhance understanding and optimize outcomes for individuals living with TSC.

Keywords: *Tuberous Sclerosis Complex (TSC), Radiological Imaging, TSC-Associated Neuropsychiatric Disorders (TAND), Renal Angiomyolipomas (AMLs)*

1. INTRODUCTION

Tuberous Sclerosis Complex (TSC) is a rare, autosomal dominant genetic disorder defined by the formation of benign tumors in various organs, including the brain, kidneys, heart, lungs, and skin(1). This condition is caused by mutations in either the TSC1 or TSC2 genes, which are responsible for coding the proteins hamartin and tuberin, respectively(2,3). These proteins regulate cell growth and proliferation(3). Therefore, their absence leads to uncontrolled cell growth, resulting in hamartomas—benign tumors composed of abnormal mixtures of cells from different tissue types(3,4). TSC affects approximately 1 in 6,000 to 12,000 live births worldwide and has a highly variable clinical presentation, with symptoms often manifesting in infancy or early childhood(1,5).

The hallmark features of TSC include epilepsy, intellectual disability, autism, and dermatological signs such as angiofibromas and shagreen patches(6). Renal involvement is also highly prevalent and can pose significant health risks, with renal angiomyolipomas (AMLs) affecting up to 70% of adult patients(6,7). In addition, TSC-associated neuropsychiatric disorders (TAND) are present in over 90% of individuals, contributing to behavioral, cognitive, and psychosocial challenges(6).

Given the multisystem involvement and complex clinical spectrum of TSC, radiology is indispensable in both the initial diagnosis and longitudinal management of the disease. Imaging modalities such as MRI, CT, and ultrasound are crucial in detecting characteristic lesions in the brain (e.g., cortical tubers, subependymal nodules), kidneys (e.g., AMLs, cysts), and lungs (e.g., lymphangioleiomyomatosis)(8,9). Early radiological identification of these features not only facilitates timely diagnosis, even before clinical symptoms appear, but also enables the monitoring of disease progression and therapeutic response(9,10). Moreover, neuroimaging supports ongoing disease surveillance and informs treatment planning, making it a cornerstone of multidisciplinary care for individuals with TSC(8–10).

2. RENAL ANGIOMYOLIPOMAS AND THEIR COMPLICATIONS IN TSC

Renal AMLs are among the most significant and potentially dangerous complications of TSC(11). While AMLs are benign tumors composed of fat, smooth muscle, and blood vessels, they can cause severe renal dysfunction and lead to life-threatening complications, such as spontaneous hemorrhage(4,12–14). These tumors often grow asymptomatically, making early detection extremely challenging(7,14). However, as they enlarge, AMLs can cause a wide range of symptoms, including flank pain, hematuria, and palpable masses in the abdomen(15,16). The growth of these tumors is often worsened by the underlying genetic mutations associated with TSC, resulting in a higher frequency and larger size of the tumors in affected patients compared to those with sporadic cases of AML(15).

As AMLs grow, the blood vessels within them may become increasingly fragile and prone to rupture(17–19). This rupture can lead to acute hemorrhage, resulting in severe abdominal pain, hypotension, or shock(12–16,18). Additionally, evidence suggests that the presence of multiple kidney lesions increases the risk of bleeding from different areas simultaneously(20). Furthermore, larger tumors, particularly those greater than 4 cm, are associated with a significantly higher risk of hemorrhage(21–23) and can lead to renal dysfunction, potentially progressing to renal failure and necessitating dialysis or even a kidney transplant(12,24). The presence of bilateral renal AMLs further elevates the risk of various complications and may require nephrectomy(25,26).

In addition to renal AMLs, individuals with TSC may develop benign tumors in the brain, which can affect multiple regions of the organ(27,28). These tumors can cause diverse neurological and psychiatric symptoms, particularly if they interfere with brain function or are located near critical structures(6,27,28). Although these tumors are often asymptomatic in the early stages, their potential to cause severe complications underscores the critical importance of regular screening(7,14).

3. NEUROPSYCHIATRIC ASPECTS OF TSC

One of the main characteristics of TSC is the presence of TSC-Associated Neuropsychiatric Disorders (TAND), which include autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), and mood disorders such as depression and anxiety(28–31). Approximately 50%–60% of individuals with TSC have cognitive impairment and learning disabilities, while about 30% of school-aged children with TSC experience difficulties in writing, spelling, reading, and mathematics(32,33). These neuropsychiatric manifestations significantly affect individuals' cognitive, social, and emotional development and can greatly impact overall quality of life(31–34).

Considering this, accurate assessment of these complex manifestations necessitates the application of standardized behavioral evaluation tools. Among the most widely utilized instruments are the Strengths and Difficulties Questionnaire (SDQ) and the TAND Checklist(35–37). The SDQ facilitates the evaluation of behavioral and emotional symptoms across multiple domains, including hyperactivity, conduct problems, and peer relationship issues(35,36). In the context of TSC, deviations in SDQ scores, particularly in domains related to hyperactivity and peer interaction, have been shown to correlate with neuroimaging findings such as increased cortical tuber burden and the presence of radial migration (RM) lines on magnetic resonance imaging (MRI)(8,38).

The TAND Checklist serves as a complementary and more comprehensive diagnostic framework, capturing six domains of neuropsychiatric dysfunction: behavioral, psychiatric, intellectual, academic, neuropsychological, and psychosocial(37). Utilization of both tools in conjunction provides a multidimensional perspective on the neurobehavioral phenotype of TSC, enabling a more precise characterization of symptomatology(35–37). This integrated assessment approach not only facilitates early and accurate diagnosis but also informs individualized intervention strategies tailored to the specific neuropsychiatric profile of each patient(39)

4. THE IMPACT OF TSC ON AUTISM, ADHD, DEPRESSION, AND ANXIETY

Autism Spectrum Disorder (ASD): ASD is one of the most common neuropsychiatric disorders in individuals with TSC, with a prevalence ranging from 40-50%, compared to only 2% in the general population (40,41). The high prevalence of the disease is believed to be linked to changes in the brain's white matter, cortical tubers, and other brain abnormalities(41–43). Children with TSC and ASD often experience significant challenges in social interactions, communication, and visual engagement, and exhibit repetitive behaviors, making early diagnosis and intervention crucial for improving developmental outcomes and social skills (41,44). Other clinical manifestations include delays in language and speech development(33,45). A study by Moavero R et al. (2019) found that 81% of patients with ASD had normal cognitive development at six months, which decreased to 67% by two years, according to BSID scores. Regarding language development, 70% of children achieved normal scores at six months, which dropped to 45% by two years(45).

Attention Deficit Hyperactivity Disorder (ADHD): ADHD is another common disorder in TSC, affecting approximately 30-50% of individuals, compared to a prevalence of 3-5% in the general population (46,47). ADHD symptoms in TSC are often linked to disruptions in the brain's executive function areas, resulting in difficulties with attention, hyperactivity, and impulse control(48). Notably, attention deficits are strongly associated with challenges in daily functioning, academic performance, and severe feelings of burnout(46,49). Research by de Vries PJ, Gardiner J, and Bolton PF (2009) indicated that 18 of 20 children (90%) with TSC faced challenges with at least one attention-related task(46). The greatest difficulty was observed in tasks requiring dual-task performance (85%), while the visual selective focus was relatively stronger(46). Furthermore, a study by Gupta A et al. (2020) provides evidence that ADHD and ASD symptoms are linked to epilepsy in TSC(50). However, no such link was found between epilepsy and mood disorders, such as anxiety or depression (50). As with ASD, early detection of ADHD in TSC patients is crucial for implementing appropriate behavioral and pharmacological interventions and assuring the best treatment outcomes(46).

Depression and Anxiety: Mood disorders, particularly depression and anxiety, are highly prevalent in patients with TSC, especially during adolescence and adulthood, and affect around 30-60% of these individuals(37,51). Depression in TSC patients is often characterized by feelings of sadness, irritability, and hopelessness(52), while anxiety may manifest as excessive worry, phobias, and panic attacks (53). These psychiatric conditions can significantly impair daily functioning, academic performance, and social interactions, necessitating comprehensive treatment strategies that may include psychotherapy and other therapies, along with medications such as SSRIs (selective serotonin reuptake inhibitors) or SNRIs (serotonin-norepinephrine reuptake inhibitors)(54,55).

5. KEY ROLE OF RADIOLOGICAL IMAGING IN TSC AND TAND DIAGNOSIS

Radiological imaging is a cornerstone in diagnosing and managing TSC. Advanced diagnostic imaging techniques are used to identify and monitor the clinical manifestations of tuberous sclerosis complex. With 85% of individuals exhibiting neuropsychiatric symptoms, there is a growing need to understand the radiological correlates of these manifestations.(33,56,57) Another point to mention is that early detection and accurate characterisation of TSC-related lesions through radiological imaging are essential for timely intervention and management (57,58). Because intellectual deficits are seen in only 40% of patients and the cutaneous and intellectual deficits are not clinically apparent in the first 2–3 years of life, the radiologic manifestations of tuberous sclerosis have taken on considerable clinical importance in the diagnosis of this disorder in infants and young children.(59) Renal involvement predominantly manifests as AMLs, which affect 70–80% of TSC patients, with larger lesions prone to hemorrhage, highlighting the importance of routine imaging surveillance(57). Additionally, pulmonary and hepatic findings, including lymphangioleiomyomatosis (LAM) and hepatic AMLs, underscore the multisystemic nature of TSC, emphasizing the need for comprehensive imaging approaches(60). This integrative use of imaging modalities enhances the understanding, early diagnosis and management of TSC's complex pathology.

6. DIAGNOSTIC IMAGING TECHNIQUES AND FINDINGS IN TUBEROUS SCLEROSIS

Ultrasound (US) is highly effective for detecting renal angiomyolipomas (AMLs). This modality allows accurate assessment of AML size and vascularity, which is essential for monitoring renal involvement(57). Computed tomography (CT) provides detailed visualisation of both renal and brain lesions, including CT excels at identifying spontaneous hematomas associated with AMLs and is particularly valuable for detecting calcified neurological lesions such as cortical tubers and subependymal nodules—hallmark features of TSC(60).

Advanced imaging modalities such as magnetic resonance imaging (MRI) provide superior soft tissue contrast, aiding in the differentiation of AMLs from other renal masses and the evaluation of lesion vascularity, with contrast-enhanced MRI being particularly beneficial for detecting subependymal giant cell astrocytomas (SGCAs), typically located near the foramen of Monro. Moreover, MRI provides critical insights into structural brain abnormalities hallmark features like cortical tubers and radial migration (RM) lines. These findings are significantly correlated with neuropsychiatric symptoms, including anxiety, ADHD, and mood disorders. MRI surpasses other techniques by offering detailed visualization of these lesions, aiding early diagnosis and management. Owing to these strengths, MRI is indispensable for early diagnosis and management of TSC.(56)

Figure 1: Male, 12 y.o. Shows cortical tubers, Abnormalities of white matter, Giant cell Astrocytoma, Subpendymal Nodules(61)

Integrating different imaging modalities is crucial for comprehensive TSC diagnosis and management. Ultrasound efficiently detects and evaluates renal angiomyolipomas, while CT and most importantly MRI provide detailed insights into brain lesions—including calcified cortical tubers, subependymal nodules, and contrast-enhancing SEGAs—thereby facilitating early diagnosis and guiding targeted interventions.

7. CORTICAL TUBERS AND NEUROPSYCHIATRIC OUTCOMES IN TSC

Cortical tubers are common findings in patients with TSC. These lesions are often visible on MRI scans and are considered one of the characteristic radiological features of TSC. Studies have shown that the number and location of cortical tubers are associated with the severity of cognitive impairment and development of psychiatric disorders such as autism and epilepsy. The presence of more extensive cortical involvement often correlates with greater severity in behavioral issues.(62,63)

Particularly in the prefrontal cortex and temporal lobes, studies had shown a higher number and a greater proportion of cortical tubers in TSC patients with ASD compared to those without ASD. These findings suggest that disruptions in neural connectivity and regional brain abnormalities play a pivotal role in the development of ASD symptoms in TSC.

Figure 2: Male, 28 y.o. Shows Cortical tubers of the cerebral cortex.(61)

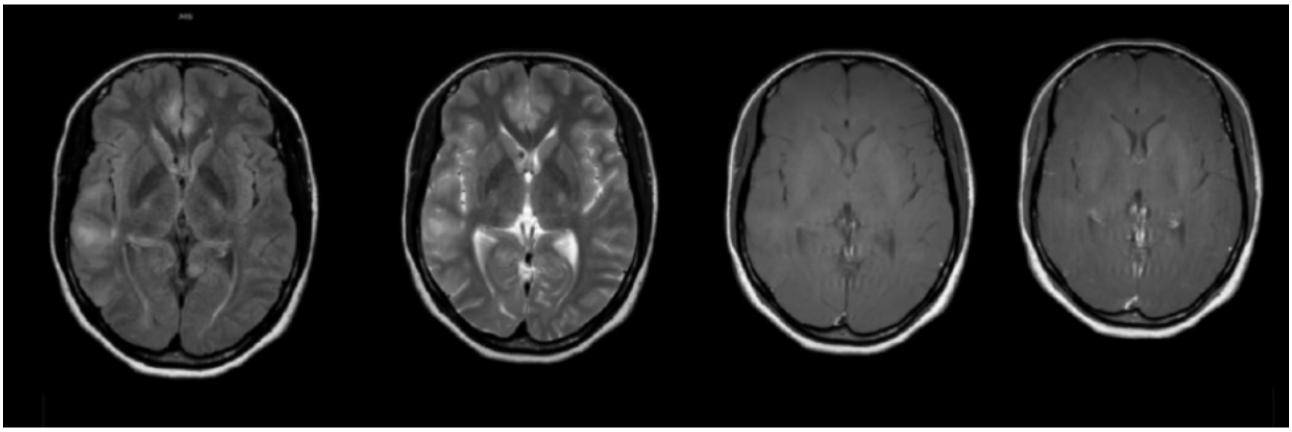
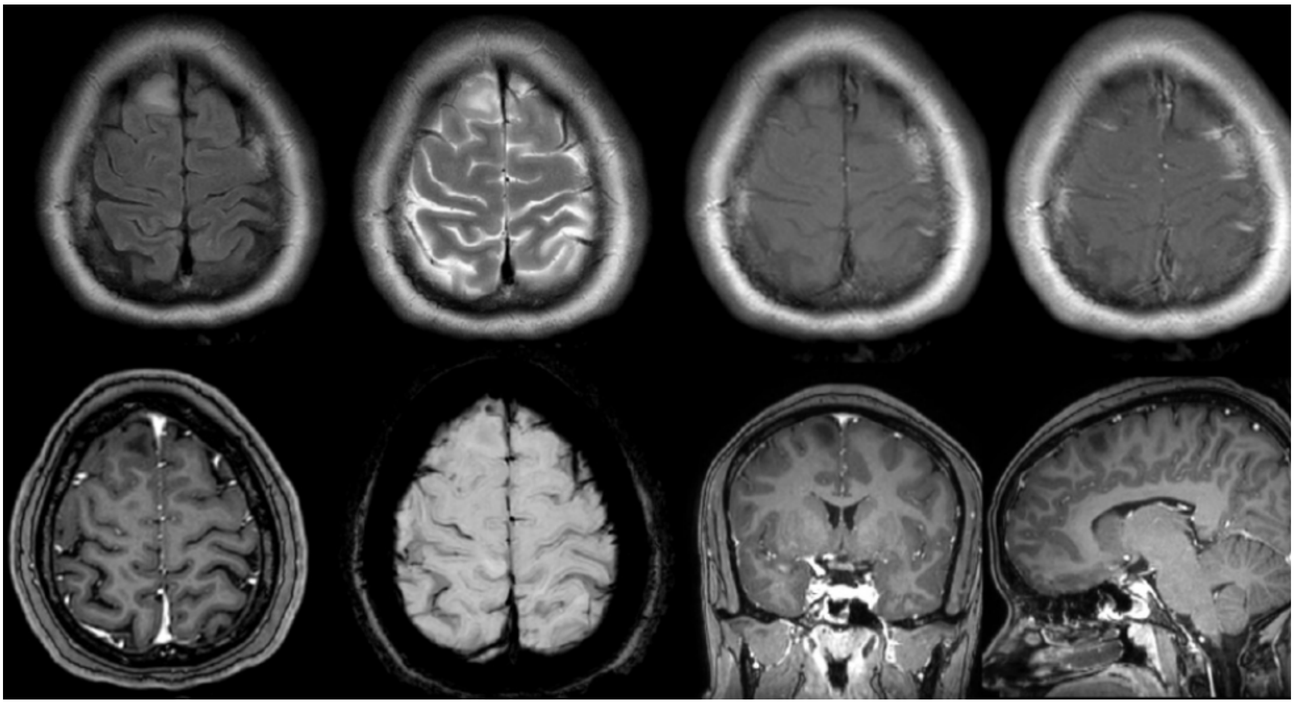


Figure 3: Male, 28 yo. Shows Cortical tubers of the cerebral cortex.(61)



Moreover, there is a prevalence of epilepsy and its relationship to neuropsychiatric outcomes, further emphasizing the impact of cortical tuber burden on cognitive and behavioural impairments.(63) Research has demonstrated that early-onset epilepsy, often linked with tuberous sclerosis, exacerbates cognitive impairments, with specific tuber distribution correlating to social and communication deficits. Additionally, functional imaging studies have identified abnormal glucose metabolism and neurotransmitter imbalances in these regions, further showing the neural mechanisms associated with TSC-related ASD.(48)

Collectively, these insights underscore the importance of integrating advanced neuroimaging techniques and early neurological assessments in the clinical management of TSC, ultimately aiming to address and mitigate associated behavioral and cognitive challenges and clinical management to understand TSC-related neuropsychiatric disorders better.

8. SUBEPENDYMAL NODULES AS MARKERS OF TSC SEVERITY

Subependymal nodules are benign lesions frequently identified on brain imaging in patients with tuberous sclerosis complex (TSC). Although these nodules are not directly associated with psychiatric symptoms, several studies indicate that their presence and burden correlate with the overall severity of TSC. This broader disease burden appears to relate, in turn, to adverse cognitive and behavioral outcomes(33,39).

Although subependymal nodules themselves are benign, a higher lesion count may indicate broader disruptions in neural connectivity. These network perturbations, particularly in brain regions governing executive function and emotional regulation, have been linked to an increased prevalence of mood disorders, anxiety, and attentional deficits (5,6). Furthermore, abnormal glucose metabolism and altered neurotransmitter profiles detected in regions adjacent to these nodules provide additional evidence of their association with neuropsychiatric impairments(7).

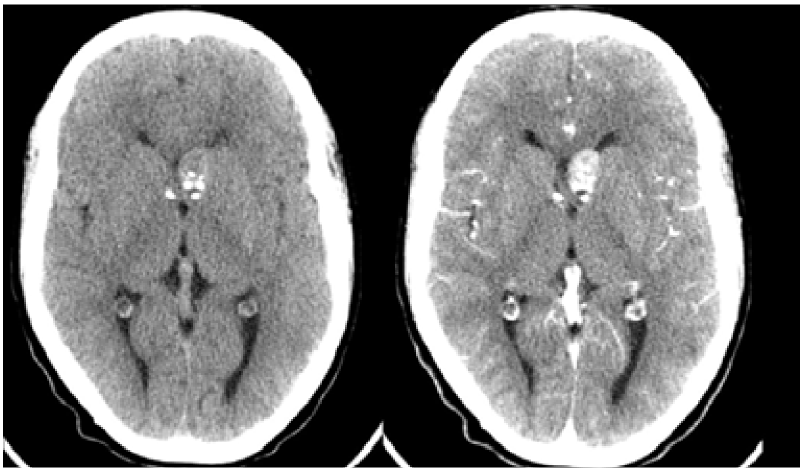
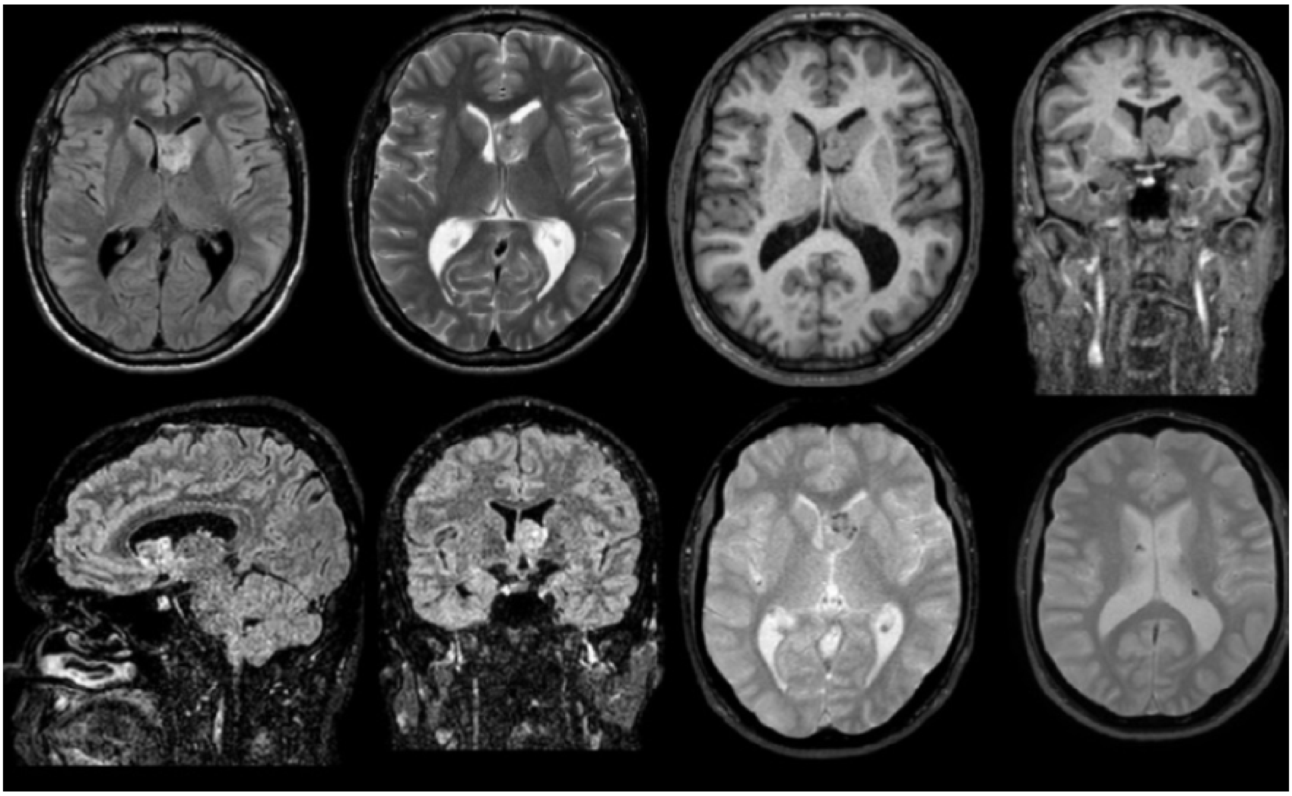


Figure 4: Male, 18 yo. Shows subependymal nodulos and SEGAS.(61)

Figure 5: Male, 29 yo. Shows Subependymal Giant Cell Astrocitomas (SEGAs).(61)



The integration of advanced neuroimaging with comprehensive neuropsychiatric assessments is essential for the early identification of at-risk TSC patients. Establishing reliable radiological biomarkers—such as the burden of subependymal nodules—can enhance prognostic precision and inform individualized treatment decisions. Early intervention strategies aimed at mitigating cognitive and behavioral impairments may ultimately improve clinical outcomes in TSC(8,9).

The distinct radiological characteristics of SEGAs—including contrast enhancement and progressive enlargement—highlight their significant diagnostic possibilities and clinical impact in TSC. Their potential to obstruct cerebrospinal fluid flow and increase intracranial pressure ultimately emphasizes the need for comprehensive evaluation and proactive, long-term monitoring to optimize patient outcomes.

9. RADIOLOGICAL FEATURES AND CLINICAL IMPACT OF SEGAS IN TSC

Subependymal nodules typically appear as calcified lesions that do not enhance with contrast, while subependymal giant cell astrocytomas demonstrate contrast enhancement. Furthermore, SEGAs tend to increase in size over time, in contrast to subependymal nodules, which generally remain stable. Notably, SEGAs are associated with significant clinical risk and account for approximately 25% of the excess mortality observed in tuberous sclerosis complex (TSC).(64,65) Subependymal giant cell astrocytoma tumors commonly occur in TSC and can impact neurological function. Their presence can lead to increased intracranial pressure, which can exacerbate symptoms of anxiety, mood disorders, and cognitive dysfunction.(66)

In rare cases, SEGAs grow large enough to obstruct the flow of cerebrospinal fluid through the lateral ventricles. This is more likely when they occur in particularly narrow passages such as the foramen of Monro, which carries fluid between the lateral ventricles and the third ventricle, and they can be found in the third ventricle as well.(67) Obstruction of this flow can cause a condition known as hydrocephalus, in which cerebrospinal fluid builds up causing the ventricles to expand, and pressure within the cranium to increase. Without intervention to relieve the pressure, hydrocephalus can cause permanent damage to the brain or, in rare cases, death.(67,68)

Compared to patients without SEGAs, patients with SEGAs were 1.83 (95% confidence interval [CI] 1.26-2.66) times more likely to have ASD. No significant relationship was found between SEGAs and intellectual disability, attention-deficit/hyperactive disorder, or major depressive disorder.(69)

Patients with subependymal giant cell astrocytomas (SEGAs) require a comprehensive evaluation for tuberous sclerosis complex (TSC) features by clinicians with specialized expertise. This assessment, particularly vital in pediatric cases, should be followed by long-term monitoring to promptly detect any changes or emerging complications.(70) Early detection of complications, such as hydrocephalus, can significantly improve outcomes by enabling immediate intervention. This proactive surveillance strategy is a cornerstone for preventing neurological deterioration and minimizing adverse impacts on patient health.(66)

10. NEUROIMAGING INDICATORS OF WHITE MATTER DISRUPTION IN TSC

Using diffusion tensor imaging (DTI), research shows significant differences in white matter properties between TSC patients and controls, reflecting disrupted axonal integrity and myelination,(71–74) particularly in the corpus callosum (75,76) in children with autism. TSC patients, especially those with autism spectrum disorders (ASD), also demonstrated lower fractional anisotropy (FA) values.(77) These findings align with the hypothesis that abnormal white matter connectivity underpins the neurocognitive and behavioral impairments seen in TSC.

Furthermore, a study has shown that white matter abnormalities in TSC patients with ASD were more pronounced compared to those without ASD, supporting the theory that altered neural circuitry contributes to the development of ASD. These results underscore the importance of integrating advanced imaging techniques into the evaluation and management of TSC-related neurodevelopmental disorders.(77)

Radial migration (RM) lines are key indicators of disrupted neuronal development. RM lines are linear bands observed on MRI, extending from the periventricular white matter to the subcortical regions.(39) These abnormalities are associated with a range of neuropsychiatric manifestations, including anxiety, ADHD, and mood disorders.(78) For instance, RM lines in specific brain regions, such as in the temporal area correlated with abnormal total scores on the Strengths and Difficulties Questionnaire. Similarly, RM lines in the parietal area are linked to heightened anxiety and extreme shyness, while their presence in the temporal region is associated with broader behavioral challenges.(79) These findings underscore the importance of advanced imaging techniques in identifying structural brain abnormalities that contribute to psychiatric symptoms in individuals with TSC.(39,80)

Therefore, advanced imaging techniques such as DTI and MRI reveal marked white matter abnormalities in TSC patients and highlight the neural basis of associated cognitive and behavioral impairments and emphasize the value of early, detailed neuroimaging in guiding timely, targeted interventions.

11. CONCLUSION

In conclusion, Tuberous Sclerosis Complex (TSC) is a multifaceted genetic disorder with significant neuropsychiatric implications, including TSC-Associated Neuropsychiatric Disorders (TAND), such as autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), anxiety, depression, and mood dysregulation. These manifestations profoundly affect cognitive, social, and emotional development, underscoring the need for early identification and intervention. Radiology remains pivotal in detecting and monitoring brain abnormalities, such as cortical tubers and radial migration lines, which are often correlated with these psychiatric symptoms. Integrating radiological findings with comprehensive neuropsychiatric assessments enables targeted interventions, enhancing the management of behavioral and emotional challenges. This highlights the essential role of multidisciplinary approaches in improving the quality of life for individuals affected by TSC.

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Radiological Insights into Chest Trauma and Subcutaneous Emphysema: A Case Report

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ABSTRACT

Massive subcutaneous emphysema is a relatively scarce but possibly serious disease that arises when air accumulates in the subcutaneous tissue [1]. We present a case of massive subcutaneous emphysema with pneumothorax, pneumomediastinum and pneumoperitoneum in a male patient with no hereditary predispositions. This case indicates that the detection of subcutaneous emphysema can be advantageous in diagnosing more serious underlying conditions. The presence of unique and uncommon radiological signs points to the fact that environmental factors are frequently underestimated. Successful outcomes depend on a holistic approach to patient management, ranging from thorough history taking and physical examination to choosing appropriate treatment and follow-up strategies.

Keywords: *Subcutaneous emphysema, Pneumomediastinum, Pneumoperitoneum, Pneumothorax, Computed tomography*

1. INTRODUCTION

Subcutaneous emphysema often causes minimal symptoms, but it can sometimes be severe and even lethal [1]. While it is typically of minor clinical importance, in rare instances it can escalate, posing risks to the patient's eyesight, breathing or cardiac function. This condition can manifest harmlessly or act as a sign of a more serious underlying health issue [2, 3]. Epidemiological information states that subcutaneous emphysema is more prevalent in males, with an average age of 54.4 ± 14.5 years [1]. Subcutaneous emphysema can arise from various processes, such as blunt or penetrating trauma, pneumothorax, barotrauma, infection, malignancy, iatrogenic subcutaneous emphysema resulting from surgical procedures, and even spontaneous occurrences [2]. Precise statistics on the occurrence of subcutaneous emphysema in pneumothorax cases are not well-established. However, it's observed in about 27% of patients with trauma and rib fractures, and in 15-20% of individuals receiving intercostal drainage for pneumothorax. In traumatic pneumothorax and in patients managed with an intercostal drain, subcutaneous emphysema can arise upon breach of the parietal pleura, establishing a direct pathway for air entry into the subcutaneous tissue. For patients with an in-situ intercostal drain and evolving subcutaneous emphysema, it is theorised that the volume of air passing through the parietal pleura from the pleural cavity to the subcutaneous tissues surpasses the volume of air being extracted from the pleural cavity by the intercostal drain. This imbalance may be attributed to the discordance in flow rates between a sizable tear in the parietal pleura and a relatively small-bore intercostal drain. Intercostal drain blockage represents an example of imbalance, with one series revealing drain blockage as the underlying cause in 6 out of 25 cases of subcutaneous emphysema following intercostal drain insertion [3]. Subcutaneous emphysema can be divided into five severity grades based on its anatomical spread, which include: the base of the neck, the entire neck area, the subpectoralis major region, the chest wall, entire neck, and the chest wall, neck, orbit, scalp, abdominal wall, upper limbs, and scrotum [1].

2. MATERIALS AND METHODS

We present a case of massive subcutaneous emphysema with pneumomediastinum in a non-smoking patient with no genetic predisposition, with alcohol abuse as a social risk factor. The patient was accidentally found by a neighbour lying on the ground with facial edema. As a result, the patient was admitted to the Emergency Department of Kaunas Clinics presenting with pain on the right side of abdomen and shortness of breath. The patient was diagnosed with traumatic subcutaneous emphysema with pneumothorax, pneumomediastinum, pneumoperitoneum, acute respiratory failure type 1 and multiple rib fractures based on clinical and radiological findings. The patient's acute complaints were treated successfully with pleural drainage and medication. With this case report the authors highlight an unusual and rare presentation of subcutaneous emphysema.

3. CASE REPORT

Here, we report a case of a 52-year-old non-smoker with alcohol intoxication and no underlying past medical history of infectious diseases, operations, allergies or comorbidities who presented with symptoms of shortness of breath, tachypnea, right-sided pain and radiologic finding of traumatic subcutaneous emphysema with pneumothorax, pneumomediastinum, pneumoperitoneum and multiple rib fractures based on clinical and radiological findings.

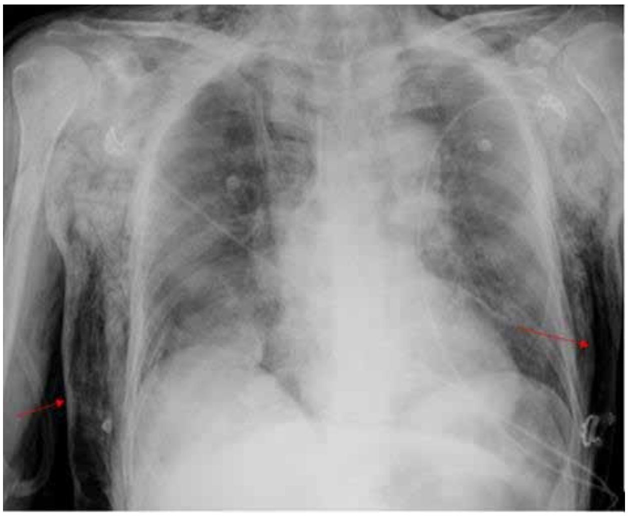
3.1 PHYSICAL EXAMINATION

During physical examination subcutaneous emphysema in the face, neck and chest was palpable. Diminished breath sounds on the right side compared to the left were observed during auscultation. The patient was responsive and oriented. The patient presented with an arterial blood pressure of 200/120 mmHg and a heart rate of 117. Breathing rate was 30 times per minute and blood oxygen saturation 90%. The ECG displayed sinus tachycardia.

3.2 CHEST X-RAY

On the day of admission plain film anteroposterior radiograph of the chest was performed. In the radiographic findings, a notable presence of high-grade intramural and subcutaneous emphysema extending prominently from the soft tissues of the neck to the upper arm and observable portion of the abdomen. The presence of extensive subcutaneous emphysema complicated the diagnostic investigation, however, such findings were assessed: on the right side of the chest, a IX rib fracture with significant dislocation and suspected fractures of VII and VIII ribs were evident; suspected fractures involved the VII and VIII ribs on the left side as well; intrapleural air was suspected on the right side with no such findings in the left side; the lower part of right lung displayed the signs of compression.

Figure 1. Chest x-ray showing subcutaneous emphysema (arrows).



3.3 CT SCAN

As eFAST was not informative due to subcutaneous emphysema, CT scan was performed. CT scan on the day of admission revealed approximately 7 cm of free air in the right pleural space, while no air was visualised in the left pleural space. No fluid was detected in the pleural spaces on both sides. Compressive changes were observed in the right lung, accompanied by a few parapleural pneumatoceles, with a higher prevalence on the right side. Approximately 3 cm of free air was noted in the mediastinum. The examination also identified multiple acute rib fractures, specifically involving ribs IV to XI on the right side, some with dislocations, and healed deformations of VIII and IX ribs on the left side. Free air was observed intra-abdominally, alongside the anterior abdominal wall that measured up to 0,9 cm in width. To conclude, the CT scan revealed that the left side of the rib cage had healed deformations, while the right side of the ribs had acute fractures. It also clarified that there was pneumoperitoneum, pneumomediastinum, massive subcutaneous emphysema and pneumothorax.

Figure 2. Axial chest CT showing right pneumothorax (arrow).

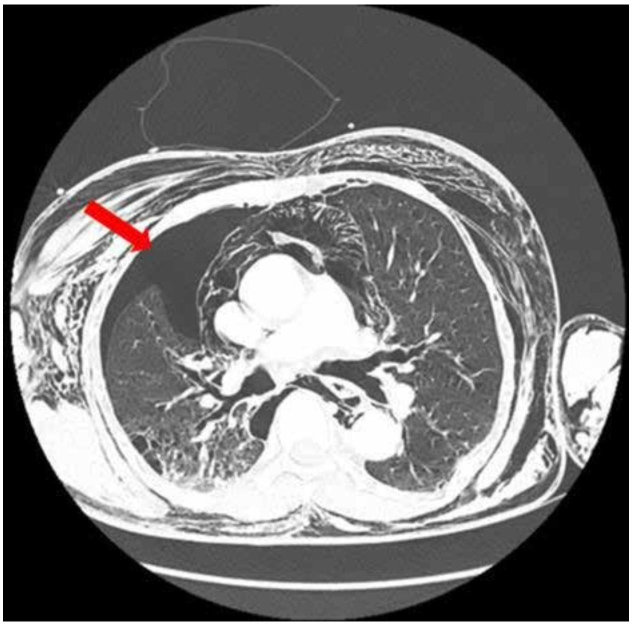


Figure 3. Axial chest CT showing pneumomediastinum (double arrow).

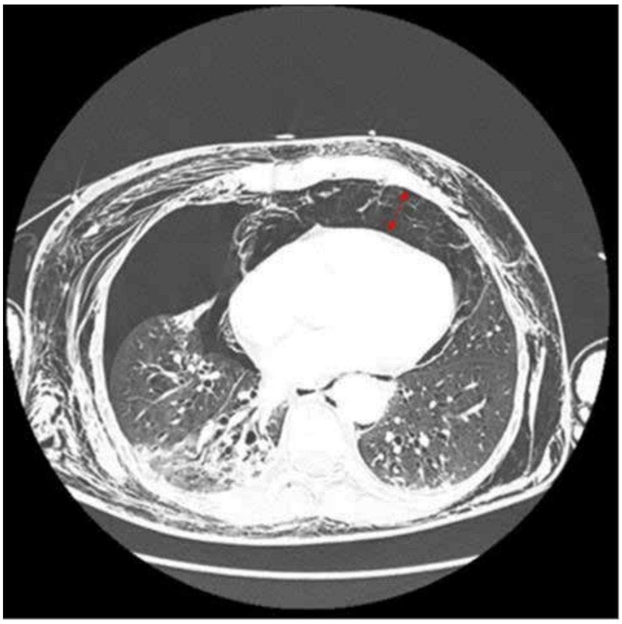


Figure 4. Axial abdomen CT showing subcutaneous emphysema (arrows).

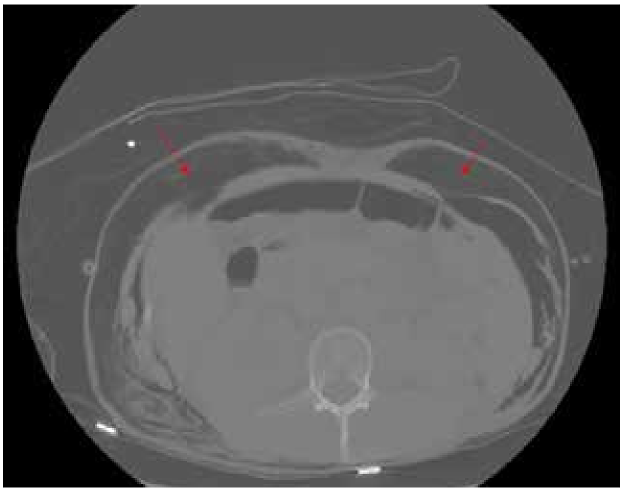


Figure 5. Axial abdomen CT showing pneumoperitoneum (arrow).

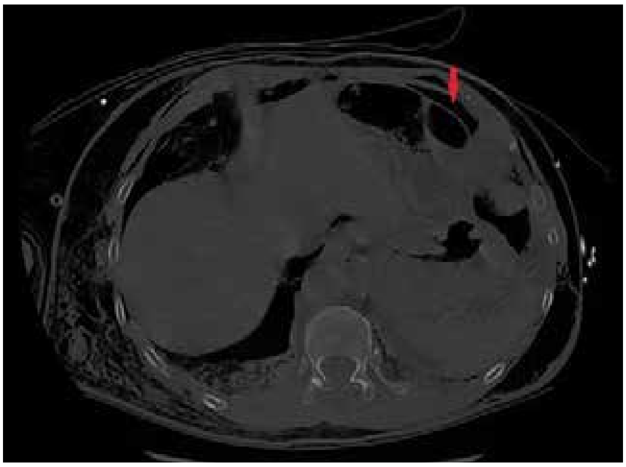


Figure 6. Axial pelvic CT showing subcutaneous emphysema (arrows).

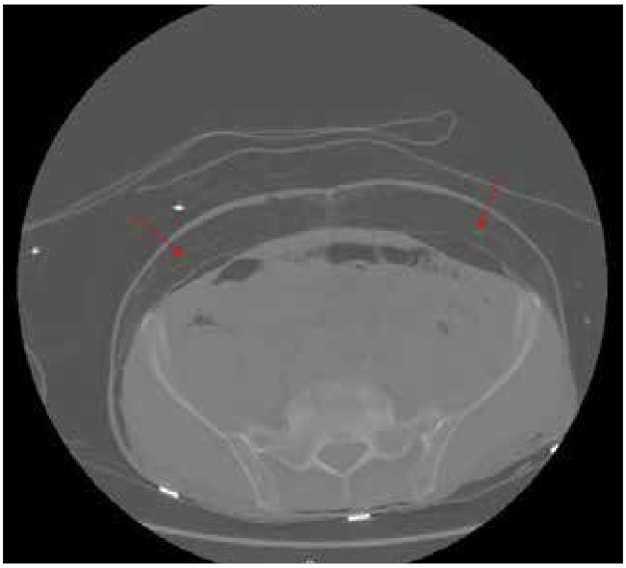
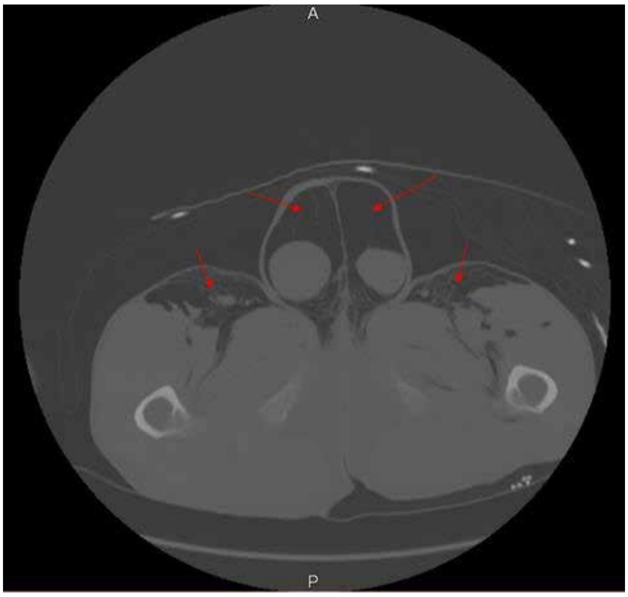


Figure 7. Axial scrotum CT showing subcutaneous emphysema (arrows).



3.4 FOLLOW-UP

Plain film anteroposterior radiograph of the chest was repeated 5 days after admission. The evaluation of pneumothorax extent was limited because of persisting massive subcutaneous emphysema. However, the aeration of the lower side of the right lung improved, fluid in pleural spaces did not appear over time and air in mediastinum decreased. These x-ray signs showed signs of recovery.

Figure 8. Chest x-ray showing positive signs of recovery.

Figure 9. Lateral chest x-ray showing positive signs of recovery.

3.5 TREATMENT

Patient was treated in the thoracic surgery unit and had a chest tube inserted for drainage of excess air. Sol. cefuroxime 1.5 g 3x/d, infusion therapy, cap. omeprazole 20 mg p/os, sol. Bemiparin sodium 3500 IU s/c was administered for five days. Patient was expected to make a full recovery and was discharged 5 days later.

4. DISCUSSION

As we discuss, the male patient aged 52, was diagnosed with massive subcutaneous emphysema, pneumomediastinum, pneumothorax, pneumoperitoneum. Our patient suffered a mechanical chest injury that was consequently specified by the patient himself. In the patient's words, he was intoxicated by alcohol, went to a bathroom, and fell. Scientific literature indicates that chest trauma remains a significant concern despite advances in trauma management. The mortality rate is variable ranging from about 10% to 60% and the incidence of chest trauma in most population groups is still high accounting for 10% of trauma admissions [4]. Thoracic injury accounts for 25% of all trauma mortality and deaths of which some are preventable by simple procedures [5]. It is discovered that alcohol dependency is associated with increased mortality, pneumonia and acute respiratory distress syndrome as well as longer stays in hospital and intensive care, therefore it is important to not overlook social risk factors while assessing the severity of chest injuries. Our patient was intoxicated with alcohol; therefore, it is important to note that dipsomania contributes to 5.3% of all deaths worldwide and increases a risk of trauma [6].

Pneumomediastinum can be caused in two main ways: as a result of blunt force trauma or as a secondary effect, often termed as secondary pneumomediastinum, during endoscopic or other therapeutic procedures [7]. In as many as 92% of pneumomediastinum cases, there is also a concurrent presence of subcutaneous emphysema, a finding that was also noted in our patient [8]. The presence of this emphysema is suggested to be a sign of injury to the respiratory tract and is almost a definitive indicator of clinically significant tension pneumothorax, with nearly 100% accuracy in diagnosis [9]. Addressing the root cause of subcutaneous emphysema should be the primary focus of treatment, as this approach typically results in the gradual resolution of the condition. For mild cases, conservative treatment while observing the patient's vital parameters is appropriate, provided the source of the problem is managed [2]. Extensive volume of air in the subcutaneous tissues can prevent the thoracic cavity from expanding and reaching appropriate tidal volumes causing desaturation, respiratory compromise with possible complications such as a cardiac arrest, therefore pneumothorax is treated with chest tube placement. In a hemothorax, however, if the tube evacuates more than 1,500 mL of blood immediately or more than 200 mL/hour, the patient should be taken to the operating room for surgical exploration of the chest. Promptly identifying and managing the underlying cause of subcutaneous emphysema is crucial for effective treatment, with conservative approaches suitable for mild cases and more invasive interventions for extensive air accumulation to prevent potential respiratory complications and ensure patient safety [2,10].

CONCLUSIONS:

The authors report a rare case of massive subcutaneous emphysema in a male patient with alcohol abuse as a social risk factor and no hereditary predispositions. Subcutaneous emphysema can be a benign symptom or a sign of a more concerning disease or condition such as rib fractures. Early diagnosis of subcutaneous emphysema causes, and management can help avoid complications and further decrease mortality. The concurrent manifestation of subcutaneous emphysema is observed with a near-universal incidence in the context of pneumothorax and pneumomediastinum. Correct assessment of injury severity is crucial as thoracic injury accounts for 25% of all trauma mortality and deaths.

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Cyst of the Canal of Nuck: A case report of a 32 year-old woman

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ABSTRACT

Cyst of the canal of Nuck in adult women is a rare condition. Clinical presentation is not specific and requires detailed assessment of radiological examination. We present a case of 32 year-old woman who had a complaint of chronic pain in the lower abdomen and was diagnosed with the Nuck cyst at the Lithuanian University of Health Sciences Hospital Kaunas Clinics.

Keywords: *nuck cyst, cyst of the canal of Nuck, hydrocele, rare diseasesg.*

1. INTRODUCTION

The development of the female gender fetus includes the process of ligamentum rotundum coming down to the same side of the labia majora and expanding along the inguinal canal. The canal of Nuck forms when with the round ligament of the uterus peritoneal evagination comes down as well [1]. This structure is equivalent to the processus vaginalis anatomical structure in men [2]. For the first time the continues presence of the canal of Nuck (processus vaginalis peritonei) was described by the Anton Nuck in 1961 [3]. In the normal circumstances inguinal canal is obliterated among girls within the first year [4]. When the canal is only partially obliterated, fluid can become trapped inside, leading to a condition known as a Nuck cyst. [5]. It is the most common type of Nuck hydrocele found with the partially closed canal. Other types such as a connecting hydrocele and a bilocular hydrocele are less common than the Nuck cyst [6].

With the failure of the closure of the canal, serious medical condition can arise - herniation of the pelvic structures [7]. Even with the extreme rarity it appears more often among children but can also occur in adult women [8]. It is known that differential diagnosis of the cyst of the canal of Nuck is troubled. Usually patients do not have symptoms of pain or painful swelling is present in the inguinal area and it is very hard to distinguish it from the sliding inguinal hernia. This is the reason why this disease is usually misdiagnosed and the incidence rate is unknown [9]. The differential diagnosis is complicated also because of the reason that up to one third cases of the Nuck cyst is related to the inguinal hernia [2]. For the primary view ultrasound examination could be used but magnetic resonance imaging (MRI) is a better option for the unclear radiological presentation [10].

Therefore, the cyst of the canal of Nuck is a very rare condition in Lithuania clinical practice with the difficult differentiation, lack of scientific literature and many radiologists remain uninformed of this anatomical pathology.

2. MATERIALS AND METHODS

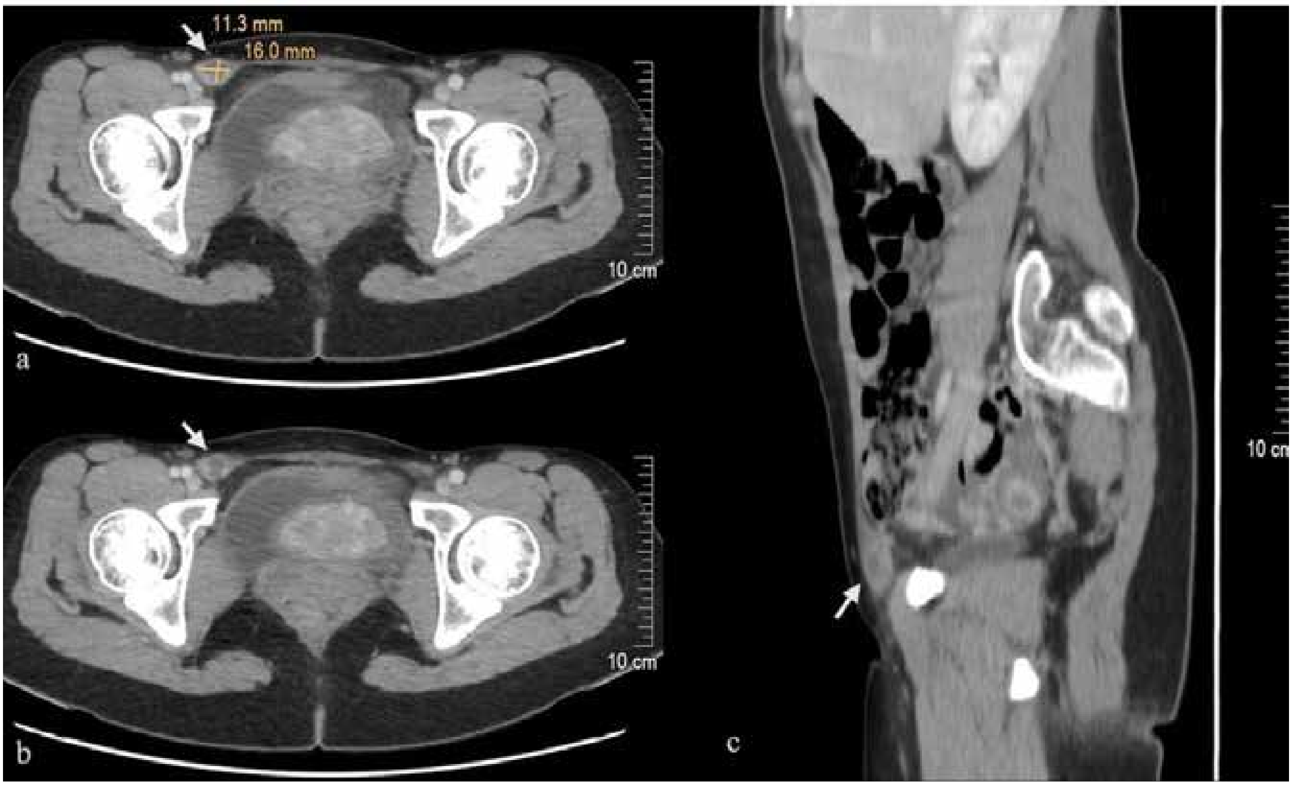
We present a rare case of the cyst of the canal of Nuck. The patient was examined and diagnosed at the Lithuanian University of Health Sciences hospital Kaunas Clinics in 2024.

3. CASE REPORT

A 32 year-old woman complained of chronic pain in the lower abdomen. The pain manifested 6 months ago and was present ever since. The patient had a history of first-degree hemorrhoids. There was neither a history of abdominal or pelvic surgery nor trauma. No prior illnesses, that could have resulted in chronic abdominal pain, were documented. Physical examination revealed tenderness in the lower right quadrant of the abdomen. No visible or palpable mass was observed. Due to suspicion of an inguinal hernia, an ultrasound examination was ordered. It revealed an elongated 1.5 × 3.6 × 1.8 cm hypoechoic cystic formation in the right inguinal region (Figure 1), and 1.5 cm strip of free fluid posterior to the uterus was also observed. The formation had no vascular flow or peristalsis. For further examination and confirmation of the nature of the cyst, a contrast-enhanced computed tomography (CECT) of the abdomen and pelvis was performed. The findings of CECT were consistent with the findings of ultrasound examination. No lymphadenopathy was present. A cystic formation, with a size of approximately 1.6 × 1.3 cm, was observed (Figure 2). Multiple strips of free fluid in the pelvic region, measuring up to 1.62 cm in size, were also reported. The cyst of the canal of Nuck was diagnosed, and a surgical treatment was decided upon. However, the patient decided temporarily postpone surgical treatment.

Figure 1. Ultrasound imaging showing an elongated hypoechoic cystic formation (white arrow).

Figure 2. Contrast-enhanced computed tomography showing a cystic formation in the right inguinal region (white arrows). (a,b) Axial view. (c) Sagittal view.

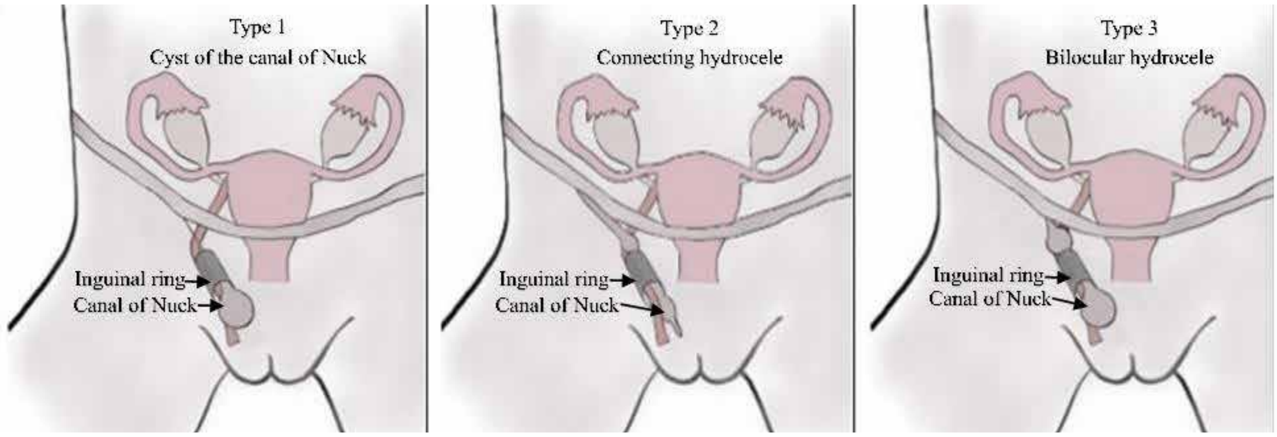


4. DISCUSSION

Overall cyst of the canal of Nuck (also called a female hydrocele) is not rarely seen among adults [8]. Its rare appearance makes a problem for the diagnosis of this disease since many of the working doctors are not familiar with this illness. The exact prevalence of the Nuck cyst is unknown. However, in the Anastasia Prodromidou et al systematic review only 16 cases of adult patients with Nuck cyst were found from 2000 to 2019 [11].

Three main types of canal of Nuck hydrocele that depend on the increase of the fluid include: type 1 cyst of the canal of Nuck that is also known as a non-connecting or cystic hydrocele, type 2 as a connecting hydrocele and type 3 - a bilocular hydrocele (Figure 3). The most prevalent type is Nuck cyst [6]. Cyst of the canal of Nuck develops when proximal side of the canal of Nuck closes but the distal part stays patent. Accumulation of the fluid in the free space is due to the disproportion of the serous fluid secretion and absorption by the epithelium [12].

Figure 3. Types of the Nuck hydroceles. Adaptated from Kohlhauser M. et al [8].



Symptoms of the cyst of the canal of Nuck usually includes swelling without a pain in the inguinolabial region [13]. Other clinical presentation can be present – painful swelling in inguinal or genital area, positive fluctuation, palpable tender mass or ecchymosis [8,11]. Our findings in the clinical case where patient had symptoms of chronic pain in the lower abdomen and tenderness in the lower right quadrant consisted with the mentioned clinical presentation in the literature but no palpable mass was observed . It is important to differentiate between an inguinal hernia and a Nuck cyst. If a bulge is visible in the standing position but disappears when lying down, an inguinal hernia is more likely to be present, rather than a Nuck cyst [13]. The differentiation of the Nuck cyst should also include other diseases such as abscess, endometriosis and benign or malignant tumors [12].

The simple and non-invasive imaging of the cyst of the canal of Nuck should be done with the ultrasound examination [14]. It is a good method to determine the diagnosis of Nuck cyst, hernia and other masses in the labia when there is a swelling in the labial region [15]. The appearance of the cyst of the canal of Nuck during the ultrasound examination varies in the literature and it is described as well-defined oval/tubular, sausage like shape, anechoic or hypoechoic cyst, with internal septum

[16]. Our findings consisted with the described Nuck cyst presentation during the ultrasound and it was seen as hypoechoic structure. Usually Nuck cysts are small with average length from 3 to 5 cm and with length of less than 5 cm with tail projection in the ultrasound examination of going towards the inguinal canal [17]. In our case Nuck cyst was measured 3.6 cm during the ultrasound examination which is slightly smaller than the average length in the literature. No blood flow can be seen with colour Dopler during the ultrasound imaging [16]. No vascular flow or peristalsis was detected in our case of Nuck cyst as well. The Nuck cyst can be differentiated from an inguinal hernia during an ultrasound examination by performing the Valsalva maneuver. This maneuver helps to exclude inguinal hernia from the diagnosis, as the Nuck cyst will not enlarge while a hernia will [11,14,18].

MRI was identified as not only a good imaging method but also as a great beneficial way to assess the extent of the cyst of the canal of Nuck [19]. It is even considered to be the first choice method of this disease since it does not consist of radiation and has an accurate view of anatomical structures. In the Michael Kohlhauser et al review of literature in the analyzed cases Nuck cyst in T1 had a hypointense signal and in T2 it was detected as a hyperintense signal [8].

Even though computed tomography (CT) is not a first choice of imaging method, among adults in emergency department it is often performed for abdominal pain or mass in the inguinal area. However, Nuck cysts can also be incidentally discovered during a CT scan for other medical conditions [12].

It is thought that surgery can be the only successful treatment for the Nuck cyst, since with percutaneous aspiration of the asymptomatic cysts recurrence was shown [6]. Surgery is also thought to be treatment of first choice due to the increased chance of the Nuck cyst caused complications, such as infection or hemorrhage [15].

5. CONCLUSION

A Nuck cyst is a very rare condition that must always be considered as part of the differential diagnosis for inguinal hernias among patients due to their similar clinical presentation. When non-typical symptoms are present, imaging should always be included in the diagnosis of a cyst in the Nuck canal, with both ultrasound examination and MRI being beneficial.

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Computed tomography (CT) examinations for pediatric patients. Current affairs of radiation protection. Literature review

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ABSTRACT

espite the risk of ionizing radiation, computed tomography is one of the most useful diagnostic radiological tests. Children are extremely sensitive to radiation exposure, and pediatric CT scans are linked to a higher risk of cancer and additional radiation side effects. Radiation safety and protection should be given special consideration for children receiving CT scans.

Keywords: *ionizing radiation, pediatric patients, computed tomography.*

INTRODUCTION

Diagnostic radiology is an essential tool in modern medicine. Computed tomography (CT) has made a name for itself as one of the most effective diagnostic radiological examinations among the diagnostic uses of X-rays [1]. It should come as no surprise that its high accuracy, quick acquisition, and accessibility have led to overuse. Although CT has substantially increased diagnostic capabilities, it does not come without potential risks - ionizing radiation is a concerning drawback of CT [2]. Most of the ionizing radiation exposure for patients undergoing diagnostic imaging is delivered by CT exams [3]. Ionizing radiation is well understood to increase the risk of developing cancer [1, 2, 4 -11] as well as tissue reactions such as cataracts and erythema, depending on the organ's sensitivity and the radiation dose [4]. CT generates ionizing radiation doses 100 to 500 times higher than traditional radiography [3]. For example, a single chest CT scan offers an effective dosage 100-1,000 times higher than a chest radiograph [4]. In fact, a patient's size, weight, use of contrast, CT machine settings, and imaging software all affect how much radiation is emitted and absorbed [3]. As it turns out, adolescents are 10-11 times more vulnerable to radiation exposure than adults [2]. Children receiving CT scans should get special attention to radiation protection. Since children live longer than the general adult population, there is a greater likelihood that harmful radiation side effects will manifest [5]. The tissue that undergoes more mitosis and contains a significant amount of hematopoietic tissue is more susceptible to the anticipated radiation exposure with an expanding population [1]. Additionally, a child's body has more water than an adult's, which causes more radiation to disperse and increases the dose needed to penetrate the same thickness [6].

According to epidemiological studies, pediatric CT scans are associated with increased cancer risk [5]. Leukemia and brain tumors are the most prevalent radiogenic malignancies in children and young adults [5, 7]. Additionally, organs and tissues outside the area of interest, such as the thyroid or the breasts, may be at risk from secondary radiation effects. Risk predictions reveal that, regardless of the age of exposure, children getting an abdominal or pelvic CT scan have a lifetime risk of 1 cancer in every 500 scans [4]. In any case, it's essential to reduce the risk of getting cancer from CT exposure while also emphasizing the necessity of defending against exposure and maximizing radiation safety [8].

The interest in and knowledge of the possible negative health effects of ionizing radiation exposure is slightly increasing nowadays. However, no control measures are taken on a global scale to lower the doses of radiation. Radiation protection is crucial, especially for children, as the use of CT has rapidly increased [8]. This report aims to draw attention to strategies for lowering unnecessary medical radiation exposure in patients under 18.

METHODS

Research papers were searched in computer bibliographic databases: PubMed, Science direct, and Springer. 18 research papers were analyzed. Information using keywords and their combinations: computed X-ray tomography, radiation exposure; X-ray, ionizing radiation, radiation dose, pediatric CT; radiation reduction.

STRATEGIES FOR REDUCING RADIATION DOSE FOR PEDIATRIC PATIENTS

Justification and optimization are two tactics for reducing CT radiation exposure [9]. According to the justification principle, ionizing radiation must have more advantages than disadvantages. The justification principle is important but also difficult to assess because it is hard to quantify. As a result, justification research is extremely rare. Excessive use of medical radiation clearly violates the principle of reason and should be avoided. Based on recent studies, approximately 25% of general population CT scans are unneeded. Unnecessary CT scans are caused by a variety of factors, including noncompliance with clinical advice, repeated scans, and a preference for CT over other imaging modalities [2]. Communication difficulties caused by developmental age, particularly in youngsters, may result in needless CT scans. Another factor leading to children's excessive utilization of CT scans is a lack of proficiency in non-pediatric institutions. A 2017 study in the U.S. discovered that children received twice the amount of radiation in CT scans in non-pediatric hospitals than at pediatric centers [2].

According to the optimization principle, the radiation dose must be kept as low as is practically and realistically achievable [9]. As stated by an investigation from 2013, a year of CT imaging for children under 15 could result in 4870 additional cancer cases. Providers need to be aware that diagnosing patients does not always require high-quality images, which subject patients to high doses of radiation. In many cases, lower-resolution scans are diagnostic [1, 6] - the highest image quality is rarely necessary to solve the clinical question [12]. Radiation doses can be significantly reduced without a relevant loss of image quality. For example, low-dose CT of the extremities compared to standard-dose CT can cut radiation dose by about 50% without affecting image quality or diagnostic performance in fracture detection [13]. One of the most efficient ways to lower the radiation exposure from CT for children is to lower the X-ray tube potential [6].

As specified by a study from 2012 in the United Kingdom, children who got an active bone marrow dose of 30 mGy or higher via CT were 3.2 times more likely to acquire leukemia, and children who received a brain dose of 50 mGy or higher were 2.8 times more likely to develop brain cancer [7]. Another study states that the cumulative ionizing radiation doses from 2-3 head CTs (60 mGy) might practically triple the chance of brain tumors, and 5-10 head CTs (50 mGy) could triple the risk of leukemia [7]. Dose reduction strategies could significantly lower the number of cancers brought on by radiation. The 75th percentile of the dosage distribution is typically set as the diagnostic reference value, and doses above that point must be justified or decreased. 43% of the cancers that are linked to pediatric CT could be prevented: effects of reducing the top 25% of doses to the median were estimated [3], which could be done by implementing pediatric CT standards that guarantee dosages to the American College of Radiology (ACR) principle "as low as reasonably achievable" (ALARA) [1]. Reduced radiation exposure and faster scan times are the two key challenges with modern CT technology that can be resolved. Combining the two approaches of cutting back on unnecessary scans and reducing the highest 25% of doses could prevent 62% of cancers linked to radiation exposure [3].

The typical practice of ordering several CT exams on the same patient increases radiation [4]. In most circumstances where CT scans are necessary for pediatric patients, a single scan is usually sufficient for diagnostic purposes [9]. High-quality pediatric CT scans require immobilizing newborns and children during acquisition to decrease motion artifacts and avoid repeat scans. One way is using various acquisition methods with faster scan capture parameters [14]. Limiting the number of phases is another technique to lower the CT dose. Multiphase scans rapidly increase the dose to an organ and are responsible for most confirmed incidents of CT overdose [15]. By performing repeated scans on the same body area, the radiation dose to the patient might be quadrupled or tripled [4, 9]. The exposure can be reduced by using correct placement, beam centering, collimation, and shielding [6]. The patient must be correctly positioned in the gantry's isocenter, and this is the radiology technician's responsibility. Off-center scanning harms the radiation distribution - the radiation exposure will increase if the patient is brought closer to the X-ray tube, making their silhouette appear larger. The patient's silhouette will appear smaller if they are farther away from the tube, limiting radiation exposure and reducing image [12]. They may also have fewer repeat exams because of insufficient or incorrect examinations. Systems based on artificial intelligence are now available to guarantee accurate central positioning. To reduce unnecessary radiation, the scanning area on the body should be confined to the area of concern. The automatic exposure-control (AEC) feature of the most recent scanner generation aids in minimizing the radiation dose associated with CT scans – it is one of the most powerful mechanisms. AEC systems analyze the body's x-ray attenuation profile in the scan range based on the scout view and regulate the tube current to maintain image quality throughout the scan [9, 14, 16].

Dual-source CT machines can cover larger areas in comparably shorter amounts of time due to the quick table speed. These scanners have the capability to reduce the need for sedation in children while still producing high-quality images with fewer motion artifacts. These machines also can use rapid ultra-high pitch scanning and a low kilovolt setting (70-80 kV) [6, 10, 17]. CT might become a low-irradiation procedure if the right protocols and dose-reduction techniques are used.

In terms of radiation protection and noninvasive imaging, the most effective radiation protection is to avoid performing a CT examination [9, 12]. Simply reducing the number of CT studies is the best way to reduce the population dose from medical radiation. When a CT scan is medically necessary, the risk is minor in comparison to the diagnostic information obtained [9]. Even though many technologies have been created to lower radiation exposure during CT scans, it is still necessary to optimize and adjust scan parameters for pediatric patients as well as to make sense of their use. Radiologists, medical physicists, and CT technicians directly oversee CT imaging procedures, allowing clinicians to influence patient radiation dose through careful consideration of evidence-based clinical algorithms. These algorithms help physicians weigh the risks and benefits of CT scans and choose imaging methods that provide the necessary diagnostic information without the use of ionizing radiation [10]. Clinical decision-making may also be influenced by European Union standards and worldwide guidelines. Kilovoltage (kV), tube current, scan time, slice thickness, and field of view all directly relate to radiation [18]. It is not possible to provide parameters for every type of CT scan because protocols differ depending on the type of scan. By using different imaging methods, a CT examination can frequently be avoided. Discussions between radiologists and pediatricians should be encouraged, especially when it's unclear which imaging technique should be applied [12].

Alternative diagnostic methods to CT need to be considered - ultrasonography and MRI. Non-ionizing radiation imaging modalities can provide answers to a wide range of clinical questions. The American College of Radiology recommends using abdominal MRI or ultrasonography instead of abdominal CT in pediatric patients with sudden abdominal pain, appendicitis, or renal calculus suspicion [11]. For the examination of pediatric inflammatory bowel disease, MR enterography has largely superseded CT enterography.

CONCLUSIONS

Understanding the ionizing radiation dosage associated with CT and radiation reduction measures is crucial for pediatric patients for the safest care. Optimizing radiation dose that is difficult to quantify is challenging. Every pediatric molecular imaging investigation should aim to gather the finest diagnostic information while adhering to the highest quality standards, in the shortest amount of time, and with the least amount of patient radiation exposure. To lower pediatric CT radiation exposure and optimize CT scan protocols in a pediatric patient, radiologist, technician, and physicist collaboration is essential. Radiologists and pediatricians must work together to optimize CT performance and radiation exposure. The As Low As Reasonably Achievable approach instructs radiologists to utilize as little radiation as possible during any imaging examination to deliver the clinical information required to make a diagnosis. After reviewing alternate imaging modalities, doing only the necessary CT scans is critical. Many of the measures covered in this article can be used to reduce radiation dose while preserving diagnostic examination quality.

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Artificial Intelligence in Oncologic Radiology: Past, Present and Future

A Brief History of AI in Radiology

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ABSTRACT

Introduction:
Artificial intelligence (AI) has undergone remarkable evolution in radiology since the 1960s, shifting from fully autonomous diagnostic goals to becoming a powerful assistive tool for radiologists. This transformation, particularly through artificial neural networks and deep learning methods, has significantly enhanced image interpretation, workflow efficiency and patient outcomes in oncologic imaging.

Aims and Objectives:
The aim of this paper is to review the historical development, current applications and future directions of AI in oncologic radiology, with a particular focus on breast and lung cancer diagnostics. The objective is to highlight how AI enhances diagnostic accuracy, supports clinical decision-making and paves the way toward personalized radiology.

Materials and Methods:
The article is a narrative literature review analyzing the progression of AI technologies in radiology. It includes studies and examples of deep learning systems, computer-aided detection (CADe) and diagnosis (CADx), with references to key AI models, such as CNNs and the CANARY system and their applications in various imaging modalities (CT, MRI, PET, X-ray).

Results:
AI systems, particularly deep learning and CAD tools, have demonstrated high diagnostic accuracy comparable to experienced radiologists. Applications in breast cancer imaging showed increased sensitivity and specificity in tumor detection. In lung cancer, AI enabled early detection, differentiation of benign vs malignant nodules and quantification of tumor heterogeneity, with significant reductions in radiologist workload. Nevertheless, limitations exist, such as lack of model generalizability and interpretability.

Conclusions:
AI is revolutionizing oncologic radiology by improving diagnostic precision, reducing radiologist workload and contributing to personalized medicine. Future advancements should focus on refining model generalizability, integrating AI into clinical workflows and addressing ethical, legal and interpretability challenges to maximize patient benefit.

EVOLUTION

Since the 1960s, artificial intelligence (AI) in radiology has evolved significantly, moving through various conceptual approaches and technological advancements [1]. Initially, researchers envisioned fully autonomous AI systems capable of interpreting medical images without human input, capitalizing on computers' potential to process large datasets and execute complex algorithms [2]. Early efforts were directed towards specific tasks, such as detecting abnormalities in mammograms via optical scanning and computer-assisted analysis. However, these pioneering attempts were limited by the technological constraints of the time, including insufficient computing power, limited access to digital image datasets, and nascent image processing techniques [3,4].

By the 1980s, a pivotal shift in perspective transformed the trajectory of AI in radiology. Recognizing the limitations of fully automated systems, researchers began to see AI as a tool to enhance, rather than replace, the expertise of radiologists [5]. The focus transitioned to developing AI-driven systems that could support radiologists by augmenting their efficiency and accuracy. This change in approach marked the beginning of AI as a collaborative technology in healthcare, designed to work alongside radiologists to improve diagnostic outcomes [6].

A central development during this period was the introduction of artificial neural networks (ANNs) into radiology. Modeled after the structure of the human brain, ANNs consist of interconnected processing nodes, or "neurons," that analyze data in parallel, emulating the function of biological neurons. ANNs' ability to learn directly from data without the need for explicit programming made them particularly suitable for medical image analysis. They excelled at recognizing complex patterns in images and making predictive assessments based on the features they identified, offering a powerful tool for radiologists seeking diagnostic support [1,7,8].

Two primary learning mechanisms emerged as essential components of ANN-based systems: supervised and unsupervised learning. In supervised learning, ANNs are trained on labeled data, where each image is associated with a known outcome, enabling the network to learn associations and improve predictive accuracy over time [9]. This approach proved especially valuable in applications such as disease classification and lesion detection, where labeled data are available. Conversely, in unsupervised learning, ANNs identify inherent patterns and relationships within unlabeled datasets, facilitating the discovery of novel features or categories without predefined labels. This adaptability allowed ANNs to continuously improve their performance, making them resilient to changes in data and enabling them to identify new diagnostic insights [10].

These developments in AI technology laid the foundation for modern applications in radiology, where AI systems serve as indispensable tools that support clinical decision-making. While fully autonomous diagnostic systems remain a challenging goal, the collaborative use of AI in radiology has shown promise in enhancing diagnostic accuracy, optimizing workflows, and ultimately improving patient outcomes [8]

CURRENT APPLICATIONS

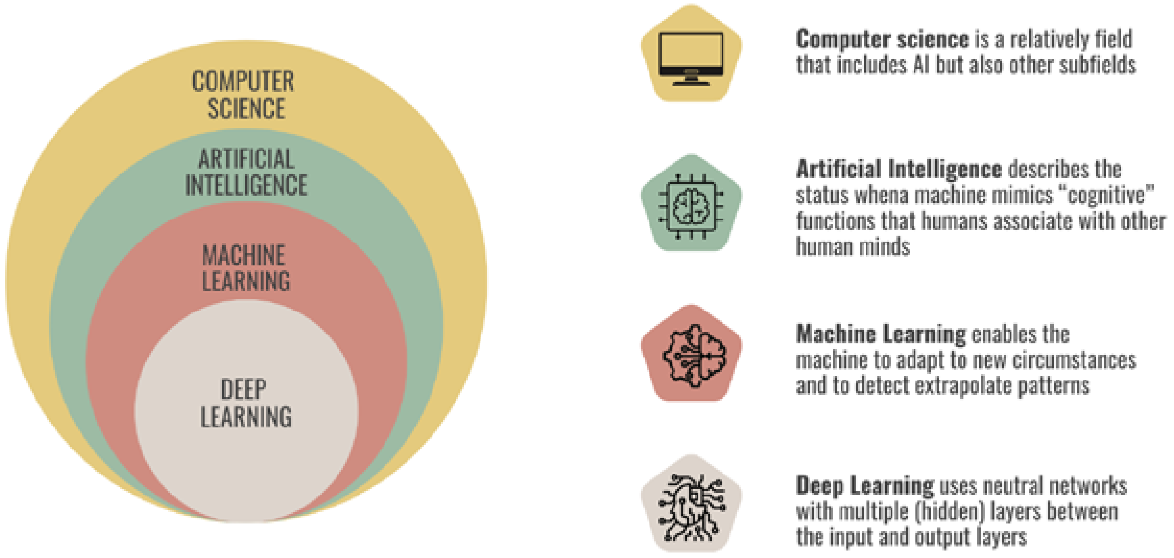
Modern radiology is increasingly incorporating artificial intelligence (AI) to enhance diagnostic accuracy, optimize workflow efficiency, and improve overall patient care [11]. The integration of AI provides numerous benefits, such as increased consistency in imaging interpretations and streamlined reporting processes [5,6]. AI's potential to transform radiology extends across various stages of the radiological workflow, from the planning of procedures to the delivery of results [11–13].

Deep Learning (DL) is an advanced form of machine learning that can independently learn and classify data without direct human intervention. DL algorithms, particularly convolutional neural networks (CNNs), are extensively used in image processing [9,13]. CNNs consist of multiple layers that analyze images, recognize patterns, and create specific filters [14]. DL is applied in a range of radiological tasks, such as detecting lesions, differentiating diagnoses, and generating automated medical reports. CNNs have been used successfully for tasks like analyzing chest radiographs to identify clinical abnormalities such as edema, fibrosis, mass, pneumonia, and pneumothorax. They can also detect knee joint abnormalities on MRI images, diagnose cerebral aneurysms through MR angiography, classify liver masses using dynamic contrast-enhanced CT images, and stage liver fibrosis via MR imaging. Additionally, DL models are employed to evaluate the genetic status of gliomas, determine the prognosis of non-small cell lung cancer using CT images, and segment organs or tissues in medical images. DL has also demonstrated capabilities in generating CT images from MR images for PET image reconstruction. Overall, DL models can achieve diagnostic accuracy comparable to that of experienced radiologists, aiding in intelligent worklist management and automated image interpretation, thereby enhancing the efficiency of radiological practices [11–13]

Computer Aided Diagnostics (CAD) is software that analyzes medical images to assist radiologists in detecting and diagnosing diseases. CAD systems can detect lesions, create differential diagnoses, and automatically generate medical reports. They are frequently used in mammography, chest x-rays, and colonoscopy. One notable example is Arterys CardioAI, an FDA-approved CAD system capable of analyzing magnetic resonance images of the heart in seconds and providing information such as cardiac ejection fraction. Additionally, CAD can be integrated with a picture archiving and communication system (PACS) to optimize radiology workflow. The integration of AI algorithms into CAD systems has further enhanced their accuracy and efficiency, enabling applications like AI software for tuberculosis detection in chest radiographs, which can serve as a standalone screening tool to reduce the need for more expensive and time-consuming microbiological testing [1,5,14].

Despite the transformative potential of AI in radiology, it is important to acknowledge its current limitations and developmental stage. The decision-making process of AI models can be difficult to interpret, and these models may not perform consistently when faced with data not included in their training sets. Factors such as differences in hospital protocols, imaging equipment, and scanning conditions can further impact AI's reliability. Additionally, there are ethical and legal concerns that must be addressed to ensure safe and responsible implementation. Nonetheless, as AI continues to evolve, it is poised to significantly enhance radiology practices and improve patient care [15].

Fig. 1. Artificial Intelligence Scheme



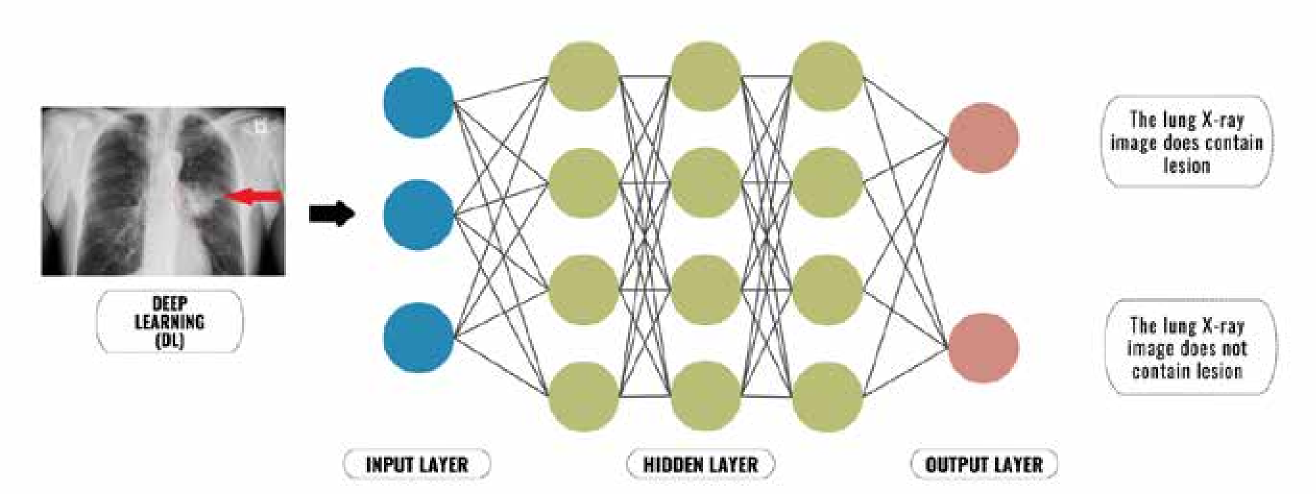
Computer science is a relatively field that includes AI but also other subfields

Artificial Intelligence describes the status whena machine mimics "cognitive" functions that humans associate with other human minds

Machine Learning enables the machine to adapt to new circumstances and to detect extrapolate patterns

Deep Learning uses neutral networks with multiple (hidden) layers between the input and output layers

Fig. 2. Deep Learning and Convolutional Neural Networks (CNN)



FUTURE DIRECTIONS

The future of AI in radiology will be closely tied to deep learning, whose strengths in pattern recognition and feature extraction make it incredibly useful for medical image analysis. As deep learning continues to advance (3D Imaging, radiomics, etc.) it will enhance diagnostic accuracy and efficiency, empowering radiologists to make faster, more reliable decisions and paving the way for precision medicine in radiology [8]. To make this process even more efficient and precise, a new perception of AI's role is emerging focusing on integrating multimodal data and enhancing collaboration between AI systems and radiologists. AI's analytical capabilities can complement the clinical judgment of radiologists, combining computational power with expert insight to deliver the best possible patient outcomes. This partnership enables radiologists to make more informed decisions, leveraging AI as an invaluable tool rather than a replacement [16–18]

AI research in radiology should be driven by focused clinical questions, aligning technological advancements with real-world needs. The PICO framework (Patient/problem, Intervention, Comparison, and Outcomes) can guide research to ensure that AI addresses specific patient issues. By centering on clearly defined clinical goals, AI in radiology has the potential to make a direct, meaningful impact on patient care, ultimately enhancing the quality and efficiency of medical imaging and diagnosis [19–21]

ADVANCING BREAST CANCER DETECTION AND DIAGNOSIS THROUGH AI-DRIVEN RADIOLOGY

Breast cancer is the most common tumour among women worldwide and, despite significant medical advancements, it remains the second leading cause of death in women. Therefore early diagnosis of this cancer has a major impact on reducing mortality. Various tools have been developed for the diagnosis of breast cancer, including mammography, ultrasound and MRI [22]. Due to image-related problems such as poor contrast, visual noise and insufficient object recognition capability, some tools have been developed to enhance image interpretation. Therefore, considering the complexity of breast cancer diagnosis, artificial intelligence (AI) can play an important role in this field [23]. The rapidly advancing field of AI is not only learning how to detect abnormalities in breast tissue, but it also serves as a tool for diagnosis, prognosis, treatment and risk assessment. Current methods for evaluating tumor response to neoadjuvant treatment include physical examination and conventional breast imaging using mammography, ultrasound and MRI. By developing the combination of MRI images with deep learning, it is possible to create precise image features that could be used to design personalized breast cancer treatment plans. Further application of artificial intelligence may have important clinical implications for individualised assessment and screening recommendations for specific patients [23,24].

Computer-aided detection (CADe) identifies and localizes objects of interest in the images, which can help to solve problems such as the dense layer of breast parenchyma covering a malignant lesion, the processing of large amounts of image data, and the physician fatigue and distraction, that hinder radiologists' ability to detect cancer. Diagnosis using the AI, known as computer-aided diagnosis (CADx), aims to identify the characteristics of the lesion and tumour markers associated with the likelihood that the detected lesion is cancerous. This system involves the automatic characterization of the region or tumor initially identified by a radiologist, followed by AI analyzing the lesion and assessing its malignancy probability [25,26].

The advantages of using the computer systems for breast cancer diagnosis include assisting radiologists in the interpretation and screening processes, reducing the number of false-positives results, thus avoiding unnecessary biopsies and reducing the time taken to examine a patient by reviewing images and providing conclusions in just a few seconds. Therefore, the role of AI in breast cancer diagnosis will continue to evolve, emphasizing that it will not replace the radiologist, but will assist them in the diagnostic process with new and effective tools [27,28].

ENHANCING LUNG CANCER DETECTION, DIAGNOSIS, AND TREATMENT WITH AI-DRIVEN RADIOLOGY

Lung cancer is the leading cause of cancer-related deaths for both men and women worldwide [29]. Despite improvements in survival rates for many cancers over recent decades, survival for lung cancer patients remains low due to late tumor detection [30]. In this context, artificial intelligence (AI) has emerged in research as an effective tool for early cancer detection and for differentiating lung nodules into benign or malignant tumors. A study conducted in 2017 used an AI model to analyze medical images obtained during screening. By examining four semantic features of the tumors (short-axis diameter, contour, concavity, and morphology), the AI successfully differentiated malignant nodules from benign ones with an accuracy of 74.3% [31]. A separate study in 2018 further demonstrated AI's potential by accurately evaluating key characteristics of small lung nodules (less than 6 mm), such as emphysema score, attachment to blood vessels, nodule location, margin definition, and concavity. Using these features, the AI provided a detailed diagnosis and prognosis at early disease stages, achieving an area under the curve (AUC) of 0.930, indicating high diagnostic accuracy [32].

Analyses of tumour heterogeneity show that while targeted somatic changes may appear clonal in one tumour biopsy, they may be completely absent in additional biopsies from different areas of the same tumour [33–35]. As tumour cells with a certain type of receptor identified in a single tumour biopsy may be subclonal, therapies targeting them would only be effective against this subset of cancer cells, while subclones of the cancer lacking these receptors would remain intact. This problem has driven the development of artificial intelligence tools designed to capture and quantify tumor heterogeneity. In trials, the CANARY (Computer Aided Nodule Assessment and Risk Yield) system [36] has demonstrated the ability to quantify radiographic characteristics in a non-invasive way, indicating tumor phenotype ($P < 3.53 \times 10-6$), prognosis, histological subtype ($P = 2.3 \times 10-7$), and key biological features, including somatic mutations [37].

Additionally, by acting as an unbiased assessor of the data during initial screening, AI can reduce the radiologist's workload by 86.7%, while avoiding false-positive results, thus contributing to the management of lung cancer screening [37,38]

CONCLUSIONS

AI in radiology has become a critical tool in enhancing the diagnostic process and improving patient care [39]. By utilizing advanced technologies like deep learning and computer-aided diagnosis (CAD), AI systems are capable of analyzing complex medical images, identifying abnormalities, and assisting radiologists in making more accurate diagnoses. These systems can detect and characterize lesions, identify early signs of diseases like breast and lung cancer, and provide automated reports, all while reducing the workload of radiologists [40,41]. AI has shown promise in identifying patterns that might be overlooked by the human eye, such as differentiating benign from malignant tumors, assessing the genetic status of gliomas, and predicting disease progression. Additionally, AI contributes to streamlining radiology workflows by reducing false-positive results, speeding up image interpretation, and enhancing overall diagnostic accuracy. Although AI has not yet reached a stage where it can replace radiologists, the future of collaboration between AI and radiologists holds great promise for enhancing patient health and improving outcomes [41–44].

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The Importance of Time in Acute Ischemic Stroke Diagnosis: From Patient Admission to Radiological Assessment: A Retrospective Study

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ABSTRACT

Acute ischemic stroke (AIS) is a medical emergency that occurs when a thrombus or embolus suddenly blocks blood flow to the brain, depriving a specific region of oxygen. If circulation is not restored in time, brain tissue damage and cell death follow. Stroke remains the second leading cause of death worldwide, making early diagnosis and rapid treatment essential to minimize neurological damage. Despite advances in research and treatment, human factors still play a role in emergency care. Triaging patients, providing consultations, selecting the right tests, and accurately interpreting results all take valuable time, which can impact patient outcomes.

Aim. This article aims to evaluate the diagnostic time values for acute strokes in one Hospital center.

Methods. A retrospective analysis of adult patients diagnosed with acute ischaemic stroke (International Classification of Diseases I63.5) in the Trauma and Emergency Department in one Hospital center, that required head enhanced CT scan.

Conclusion. Most door-to-CT orders were placed within five minutes, with a median time from door to CT interpretation of 1 hour 5 minutes. While reducing this delay is crucial for AIS management, the lack of of significant differences between shifts suggests operational factors play a role. To improve efficiency, future efforts should prioritize minimizing the interval between CT completion and radiological interpretation.

INTRODUCTION

Acute ischaemic stroke (AIS) is an urgent condition in which blood flow to the brain is suddenly decreased by thrombus or embolus. This occlusion disrupts the oxygen supply for the particular area of the brain, which leads to brain tissue damage and cell death – penumbra if blood flow is not restored in time. Stroke can be divided into two groups: ischaemic stroke, which accounts for the majority of cases (about 80%), and haemorrhagic stroke [1]. Even though ischaemic stroke is more frequent, but hemorrhagic stroke is responsible for more deaths and disability-adjusted life-years lost [1]. The majority (90%) of strokes are supratentorial; as such, the public can be taught to recognize and act upon stroke using the acronym FAST, for facial droop, arm drop, speech disturbance and time [2] - neurologic deficits of sudden onset. However stroke syndrome symptoms depend upon the affected region of brain, which in turn is defined by the arterial anatomy involved.

Till this day stroke is the second leading cause of death worldwide [3]. With the global population aged 65 and over growing faster than all other age groups, the incidence of stroke is also increasing [4]. According to the World Stroke Organisation, one in four adults over the age of 25 will suffer a stroke in their lifetime [5]. However, it should be noted that the incidence of stroke increases around the age of 40, most commonly in male patients of this age [6]. The biggest risk factors for stroke are modifiable: smoking, dyslipidaemia and arterial hypertension, [6, 7, 8]. In addition, risk factors for hemorrhagic and ischemic stroke are similar, but there are some notable differences, for example: Hypertension is a particularly important risk factor for hemorrhagic stroke, though it contributes to atherosclerotic disease that can lead to ischemic stroke as well. Hyperlipidemia, on the other hand, is a particularly important risk factor for strokes due to atherosclerosis of extracranial and intracranial blood vessels [1], just as it is a risk factor for coronary atherosclerosis [1].

The timing of stroke diagnosis and the beginining of treatment is critical to prevent or minimize neurological deficits in the patient. To confirm the diagnosis of AIS or other nonstroke diagnosis, CT scan is one of the best choices for radiological test of patients with AIS F.A.S.T. symptoms [6]. Noncontrast CT scan is performed, which helps to not just diagnose the damaged area but helps to reject intracerebral haemorrhage and allows a firm prescription of thrombolytic therapy [9]. It is important to note that the diagnosis of AIS is multidisciplinary and requires the involvement of neurologists, radiologists and emergency physicians – stroke team. Despite advances in research and treatment, emergency departments are not without the human factor. Triaging, counselling, selecting the right tests and interpreting them correctly takes valuable time.

As mentioned earlier, stroke is an urgent condition and time is crucial in treatment. If symptoms are onset <4.5h, current guidelines recommend intravenous thrombolysis such as alteplase. If symptoms are onset over 6 h, then mechanical trombectomy is considered [9]. Clinical AIS end depends on the time administration of acute therapies - door to needle time which means patients in 60 minutes or less after coming to Emergency department receive IV thrombolysis. This can be divided into Door to image time – interval from patient admission to ER to Brain CT scan and Image to needle time, making it easier for tracking efficiency in stroke diagnostics and optimization [10, 11, 12]. When door-to-image time is compared to image-to-needle time, the latter has a greater impact on therapy delay [11]. Although time is important in stroke diagnosis, there is very little information and guidance on how quickly a radiologist should provide a CT scan report. In this article, we focus on the role of the radiologist in the diagnosis of stroke and radiological report of CT scan to

AIMS AND OBJECTIVES

In this study, we aim to evaluate the diagnostic time values for acute strokes in the Hospital of Lithuanian University of Health Sciences Kaunas clinics emergency department from June 2022 to August 2022, to evaluate how long it took on between a patient's arrival at Kaunas clinics emergency department and the placement of the order for a brain CT scan (door to CT order time), how quickly patient was transferred to CT scan room after ordering scan (door to CT initiation time), how quickly a radiologist provided an answer to CT scan time by reviewing door to interpretation time and radiological turnaround time(Fig. 5). Assess the work of Kaunas clinics emergency department efficiency during three work shifts: first 8:00-14:00, second 14:01-20:00, third 20:01-7:59 and evaluate the relationship between work shifts and radiological turnaround time ratings.

MATERIALS AND METHODS

Permission from the Kaunas Regional Biomedical Research Ethics Committee has been obtained. A retrospective analysis of patients diagnosed with acute ischaemic stroke (International Classification of Diseases I63.5) in the Trauma and Emergency Department of Kaunas Clinics, Lithuanian University of Health Sciences, between July 2022 and August 2022 was performed. In the analysis were included all adult patients (18 years old and older) who had acute ischaemic stroke symptoms and required head enhanced CT scan.

RESULTS

Door to CT order time. 2. Door to CT initiation time (Fig. 1)

	N		Median		Minimum		Maximum		% of Total N	
Time Groups	*1	*2	*1	*2	*1	*2	*1	*2	*1	*2
<=5 min	34	5	0:03	0:04	0:00	0:03	0:05	0:05	23,9%	3,5%
6-10 min	26	8	0:08	0:09	0:06	0:06	0:14	0:09	18,3%	5,6%
11-20 min	30	37	0:15	0:16	0:11	0:11	0:20	0:20	21,1%	26,1%
21-30 min	25	20	0:26	0:23	0:21	0:21	0:30	0:30	17,6%	14,1%
31-60 min	21	49	0:40	0:42	0:31	0:31	0:57	1:00	14,8%	34,5%
>60 min	6	23	2:26	1:14	1:13	1:02	9:34	9:50	4,2%	16,2%
Total	142	142	0:14	0:31	0:00	0:03	9:34	9:50	100,0%	100,0%

We reviewed 142 cases of head CT scans for suspected acute stroke (I63.5). First, we summarize the descriptive statistics for the Door to CT order time across different time rating categories. Most cases fall into the categories of ≤5 minutes (34 cases, 23.90%) and 11-20 minutes (30 cases, 21.10%), highlighting the most common durations for CT order times. The median door to CT order time increases progressively with the categories, ranging from 3 minutes (≤5 min) to 2 hours and 26 minutes (>60 min). The minimum time for CT order was 0 minutes, while the maximum time extended to 9 hours and 34 minutes (Fig.1). The summary of the Door to CT initiation time across categorized time intervals: The median door to CT initiation time was 31 minutes, with a range from 3 minutes to a maximum of 9 hours and 50 minutes. The largest proportion of cases (34.50%) falls within the 31-60 minutes category, followed by 11-20 minutes (26.1%). Together, these two categories account for more than half of all cases (Fig.1). Door to CT interpretation time across categorized time intervals. The median door-to-CT interpretation time is 1 hour and 5 minutes, with a range from 21 minutes to a maximum of 10 hours and 7 minutes. The majority of cases (54.9%) fall in the >60 minutes category (Fig. 2).

Door to CT interpretation time (Fig. 2)

Door to CT interpretation time rating	N	Median	Minimum	Maximum	% of Total N
20-30min	10	0:29	0:21	0:30	7,0%
31-40min	17	0:36	0:31	0:40	12,0%
41-50min	16	0:45	0:41	0:50	11,3%
51-60min	21	0:56	0:51	1:00	14,8%
>60min	78	1:26	1:01	10:07	54,9%
Total	142	1:05	0:21	10:07	100,0%

Radiological turnaround time across different work shifts: First shift (08:00–14:00) median of 28 minutes (range: 9 minutes to 2 hours and 32 minutes); Second shift (14:01–20:00) median of 31 minutes (range: 5 minutes to 1 hour and 42 minutes); Third shift (20:01–07:59) median of 28 minutes (range: 13 minutes to 1 hour and 36 minutes) (Fig. 3 and Fig. 6). We used non-parametric independent Samples Kruskal-Wallis test to evaluate if the distribution of turnaround time is the same across categories of work shift. Based on the data from the research, it can be stated that there is no difference between turnaround time and three categories of wok shift (H = 2,5; P=0,286).

Radiological turnaround time across different work shifts (Fig. 3)

Work shift	**N**	**Median**	**Minimum**	**Maximum**
First shift(08:00-14:00)	45	0:28	0:09	2:32
Second shift(14:01-20:00)	49	0:31	0:05	1:42
Third shift(20:01-7:59)	48	0:28	0:13	1:36
Total	142	0:29	0:05	2:32

Another study was conducted using non - parametric chi-square test to determine if there is a relationship between the turnaround time, which we put into 4 categories: ≤20 min, 21–30 min, 31-40 min, >40 min; and three work shifts. The analysis indicates that turnaround time ratings are not significantly associated with the work shift. This finding suggests that work shift variations do not influence turnaround time (χ2 = 4,486; rcr=0,126; P=0,611) (Fig. 4).

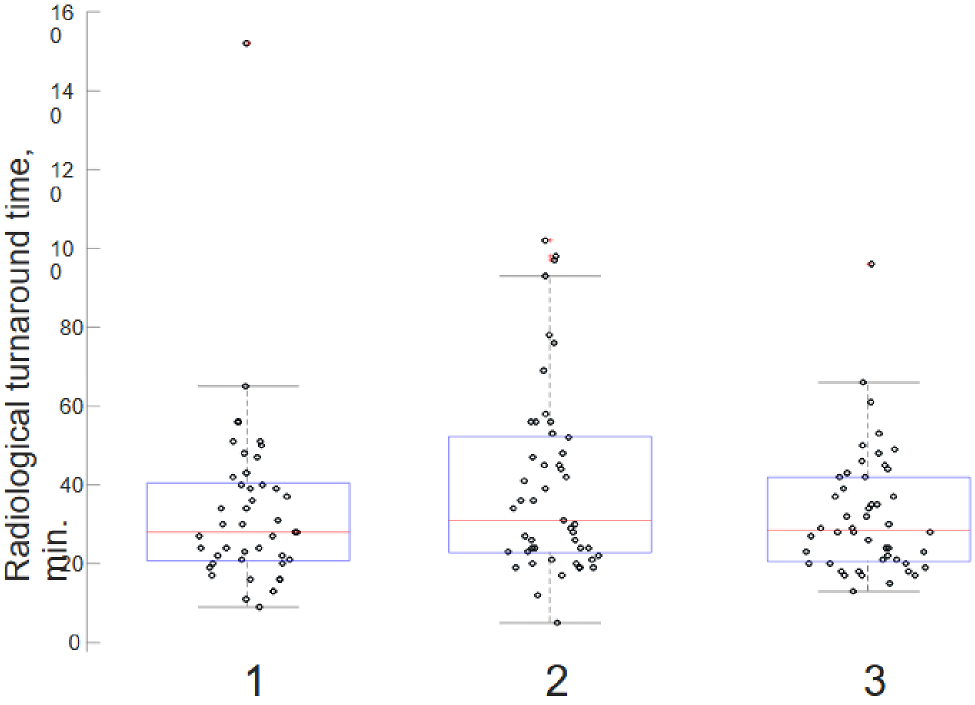
Turnaround time rating * Work shift Crosstabulation (Fig. 4)

Count

First shift(08:00-14:00)		**Work shift**			**Total**
		Second shift(14:01-20:00)	**Third shift(20:01-7:59)**		
Turnaround time rating	<=20 min	11	9	12	32
	21-30 min	14	15	15	44
	31-40 min	9	5	8	22
	>40 min	11	20	13	44
Total		45	49	48	142

DISCUSSION AND CONCLUSION

Analysis of door-to-CT order time showed that most orders were placed within ≤5 minutes (23.9%) and 11-20 minutes (21.1%), with the median time increasing progressively across categories. However, the wide range (0 minutes to 9 hours and 34 minutes) suggests that some cases experienced longer delays that could affect outcomes. The Door to CT initiation time showed a median of 31 minutes, with most cases falling within 31–60 minutes (34.5%) and 11–20 minutes (26.1%). While this represents an efficient workflow in many cases, some patients faced delays of up to almost 10 hours. Median time from door to CT interpretation: 1 hour 5 minutes. 54.9% of cases >60 minutes. Reducing this time is crucial in managing AIS. There was no statistically significant difference (P=0.286) between shifts in radiological turnaround time for different work shifts, suggesting that stroke diagnosis is performed equally across all shifts. Furthermore, chi-squared analysis (P=0.611) showed no significant association between turnaround time categories and work shifts. The absence of significant differences between shifts suggests that delays are not time-sensitive but may be caused by other operational factors. To enhance efficiency, future efforts should focus on reducing the time from CT completion to radiological interpretation.



STATISTICAL ANALYSIS

IBM SPSS Statistics 29 was used for data analysis. The analyzed quantitative variable radiological turnaround time did not meet the conditions of normal distribution and it was therefore compared in three groups (by shifts) using the non-parametric Kruskal–Wallis test and if pairwise comparisons will be needed it will be done using Dunn's test with applied Bonferroni correction. The results were described in medians together with minimum and maximum values (Min–Max). The relationship between qualitative variables was analyzed using the χ2 test of independence, pairwise comparisons, and Cramér's coefficient. The results were described in terms of frequency and relative frequency (percentage). The observed differences and dependency were considered statistically significant if the calculated P-value was below 0.05.

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Factors Influencing the Interest in Radiology Among Medical Students, Residents, and Physicians: The Role of Artificial Intelligence

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ABSTRACT

Radiology is a medical specialty that is becoming increasingly significant due to technological progress, particularly the development of artificial intelligence (AI). However, students' and doctors' perceptions of this field are influenced by various factors that can shape their professional choices. This study set out to understand how students, residents, and radiologists themselves view radiology as a specialty and to determine what role AI plays in their decision-making process.

The study was conducted over three months, from October 2023 to January 2024, with a total of 182 respondents participating. These included 98 medical students, 33 radiology residents, and 51 practicing radiologists. Data were collected through an anonymous questionnaire tailored to each group. The responses were analyzed using statistical methods to identify patterns and significant associations.

The findings revealed that students most valued flexibility in work schedules and the possibility of remote work or employment abroad. However, 70.4% stated that they did not see radiology as their future profession. Residents highlighted subspecialization opportunities and the growing impact of AI on reducing diagnostic errors. Practicing radiologists placed emphasis on salary prospects, compatibility with personal preferences, and limited direct patient contact.

Although AI is seen positively across all groups, students were the least likely to consider its development as a decisive factor when choosing radiology. In contrast, residents and doctors increasingly recognized AI's potential to support diagnostic processes and reduce human error.

The results suggest that medical schools and residency programs should place greater emphasis on radiology's technological advancements and practical applications to better align students' perceptions with the reality of the specialty. More practical exposure to radiology and its integration with AI could enhance its appeal to future healthcare professionals.

Keywords: *Radiology, Medical Education, Career Decisions, Artificial Intelligence.*

LITERATURE REVIEW.

Radiology is a field that is an essential part of the healthcare system, enabling the diagnosis and treatment of patient diseases in a variety of medical fields [1]. Diagnostic radiology has been considered as one of the most competitive medical specialty areas for some time. According to statistical data, the number of entrants to the specialty of diagnostic radiologist in Lithuania has been increasing steadily. The number of admissions to medical radiology between 2016 and 2020 is increasing. The demand for radiologists in clinical work is also increasing [2]. According to the NIS statistics, the need will increase to 451 specialists in 2032, while the actual number of specialists in 2022 is 410 doctors [3]. It is speculated that factors such as an uncertain labor market, misconceptions about the specialty, daily monotony or the limited patient contact known to many, may cause medical students to hesitate to pursue radiology as a specialty. To secure the future of diagnostic radiology, it is important to ensure that medical students make informed career choices that they can enjoy [4]. Many studies have been conducted to identify the factors that influence students' choice of specialty. Specialties are often grouped into categories such as: flexible lifestyle, surgery or primary care. With its generally stable working hours and salaries, radiology is often described as "the epitome of a career for life"[5]. A recent study has shown that direct patient contact and intellectual challenge are the most important factors in deciding whether radiology is a career choice for future medical students [6]. However, in recent years, technological innovations based on artificial intelligence (AI) have raised speculation about the future of both diagnostic and interventional radiology and the long-term viability of clinical practice." Andrew Ng, founder of Google Brain Deep Learning, told The Economist that AI will replace radiologists before their assistants. Since the promotion of the use of AI in radiology, the number of students choosing radiology as a specialty in France has fallen. Thus, radiology, which was the most attractive specialty in 2012, was only ranked 7th in 2017 when comparing attractiveness indices [7]. Currently, AI is dominating more conferences and the literature, and is only just beginning to be applied in clinical practice. In a study conducted in 2021, it was noted that there is still a fear that specialists will be replaced by AI, as 39% of respondents reported this. Nearly half of the respondents, 48%, expressed an open and active attitude towards the AI. This study also found a significant relationship between an open and active attitude towards the AI and male gender, older age, scientific education, professional use of social media and knowledge of informatics/statistics. This indicated that radiology residents and radiologists are inherently positive about the latest technological developments in AI, especially those who have most of their careers ahead of them and those who are intrinsically more likely to be interested in science and technology[8].

The choice of a medical specialty is a dynamic relationship between students' expectations, the expectations of the medical specialty and the competitiveness of the specialty [9].One study conducted in 2019 determined how, when, and why radiology residents became interested in radiology and how these factors correlated with job satisfaction. What was interesting and unexpected in the study was that the results showed that the majority of current residents first became interested in radiology outside of their radiology specialty training. This is particularly important as it demonstrates that we can positively influence student interest in radiology regardless of whether or not there is a radiology clerkship at the institution. This study also found that residents who chose radiology for its intellectual component were significantly more satisfied with their jobs than those who chose it for its flexible lifestyle. Although not the most important factor, lifestyle was cited by as many as 80% of respondents in this study as a reason for choosing radiology [4]. In a systematic literature review, seventeen studies assessed the impact of artificial intelligence on the future of radiologists' work. In six studies, radiology physicians and radiology technologists were asked whether they would choose radiology again given their current knowledge of AI. In all six studies, the majority of participants (63.8-93.7%) denied that they would be willing to change their specialty, regardless of their current knowledge of DI [10]. So we wondered what students, residents and doctors at our institution think and what aspects determine their choices here. What are the attitudes of current or future physicians towards the emergence of DI in clinical practice and how does this change the students' perception of the specialty. This is why it is important to fully understand when and why medical students become interested in radiology and, more importantly, what factors are ultimately related to future job satisfaction and how existing doctors and residents feel about the specialty.

RESEARCH METHODS:

The study duration was from October 1, 2023, to January 1, 2024. The study received approval from the LSMU Bioethics Center (No. 2023-BEC2-273).

Data were collected through a prospective study using an anonymous questionnaire. An original four-part questionnaire was used. The first part contained demographic data, the second was intended for students, the third for resident doctors, and the fourth for radiologists. Data analysis was performed using the statistical data analysis package "IBM SPSS Statistics 29.0", examining the chi-square (χ^2) test, the z-test, frequency tables, and the paired Student's t-test. A statistically significant difference was considered when $p = 0.05$ or $p < 0.05$.

1. DEMOGRAPHIC DATA

A total of 182 respondents participated in the survey, including 98 (53.8%) students, 33 (18.1%) resident doctors, and 51 (28%) physicians. A notable gender difference was observed among respondents: 122 women (67%) and 60 men

(33%). The respondents were divided into three age groups: 18–24 years old (43.65%, n=79), 25–34 years old (40.33%, n=73), and over 35 years old (16.02%, n=29). One respondent provided an incorrect answer to the age question.

2. STUDENT'S KNOWLEDGE, INTEREST, AND OPINION ON THE RADIOLOGY SPECIALITY

A total of 98 students (53.85% of all respondents) participated in the study: 53 from the fourth year (54.1%), 30 from the fifth year (30.6%), and 15 from the sixth year (15.3%). Gender distribution among students was uneven—78.6% of participants were women, and 21.4% were men. All students, regardless of their academic year, reported being familiar with the radiology specialty, with 97 respondents (99%) indicating that their first encounter with the specialty occurred through university lectures, seminars, or practical work. Additionally, 28.6% of students stated that they knew radiologists who introduced them to the specialty.

INTEREST IN THE SPECIALITY

A total of 70.4% of students did not consider radiology as a future specialty, which could be related to a lack of practical experience or how the specialty is presented. Only 17.3% of fourth- to sixth-year students (seven from the fourth year, seven from the fifth year, and three from the sixth year) considered radiology as a career path, revealing a trend of declining interest in the specialty in higher academic years. When asked to rate their interest in radiology on a scale from 1 (not interested) to 10 (very interested), only 6.1% of respondents selected the highest rating, '10.' The possibility of a flexible work schedule was the most important factor for most students, while human anatomy was rated as the least interesting aspect.

INFLUENCE OF ARTIFICIAL INTELLIGENCE (AI)

The study also aimed to assess student's views on AI's influence on their choices. A statistically significant association was found between student's gender and their views on AI's impact on radiology. Women were more likely to answer "No" (84.9%) to the question "Does AI development influence your choice?" compared to men (15.1%), who more often acknowledged AI's impact. A very weak but statistically significant association (p = 0.050) was also found, suggesting that AI development influenced student's decisions to consider radiology as a future specialty. This indicates that while AI is seen as an important factor in radiology, it has not yet become a primary motivation for choosing this specialty.

Fig. 1. Aspects That Make Radiology an Appealing Specialty

Mean/Median	**STUDENTS (n=98)**	
	Mean	**Median**
Flexible work schedule	4.21	5.0
Opportunities to work in foreign hospitals	4.1	5.0
Possibility to work remotely	4.05	5.0
Salary potential	3.87	4.0
Broad opportunities for subspecialization in various fields	3.63	4.0
Interesting due to this specialty's great prospects in technological advancements	3.24	3.0
Possibility to become an interventional radiology specialist	3.13	3.0
Feedback from senior students, residents, and doctors about the specialty	3.07	3.0
Limited contact with patients	2.71	3.0
Learning new things every day	2.69	3.0
Opportunities for scientific research	2.67	3.0
Wide possibilities of artificial intelligence in radiology	2.66	3.0
I am interested in radiological image analysis, description, and interpretation	2.51	2.0
Interest in human anatomy	2.46	2.0

3. KEY FINDINGS ON RESIDENT DOCTORS

A total of 34 resident doctors participated in the survey. Their distribution by residency year was as follows: 17.6% in the first year, 26.5% in the second year, 35.3% in the third year, and 20.6% in the fourth year. When asked, 'When did you first become interested in radiology?' most (61.8%) answered during their first to fourth years of study, 23.5% during their fifth to sixth years, and 14.7% outside of their studies. When asked whether their current radiology studies met their expectations, 55.9% said they did, but 20.6% were uncertain, 17.6% were disappointed, and 5.9% considered changing specialties. The majority of respondents (73.5%) believe that the radiology specialty is only partially compatible with their personal life, 20.6% state that it is fully compatible, while the remaining respondents believe that it is not compatible at all. Interestingly, 91.2% of resident doctors would recommend their specialty to future doctors, which indicates the promising future prospects of the radiology specialty.

RESIDENT‘S EVALUATIONS

When resident doctors were asked to evaluate various aspects on a scale from 1 (not interesting) to 5 (very interesting), the wide opportunities for subspecialization in the specialty were rated as one of the most interesting aspects (mean=4.04), while becoming an interventional radiologist was the least appealing (mean=2.12). The compatibility of personality, interests, and abilities with the radiology specialty was rated quite highly in both groups (mean=3.64 among residents and mean=3.75 among physicians). This indicates that both physicians and residents recognize the compatibility of this specialty with their professional and personal qualities.

INFLUENCE OF GENDER ON CHOICE

Statistical analysis revealed a significant association between gender and the importance of a flexible work schedule when choosing the radiology specialty (p=0.029). Women more often indicated that a flexible work schedule had a moderate influence on their choice, compared to men, who more frequently rated this aspect as of little importance. These results suggest that work schedule flexibility is more important for women, possibly due to the desire to balance professional and personal needs. Women also more frequently reported that contact with patients had a major influence on their choice of radiology, whereas men more often rated patient contact as of moderate importance.

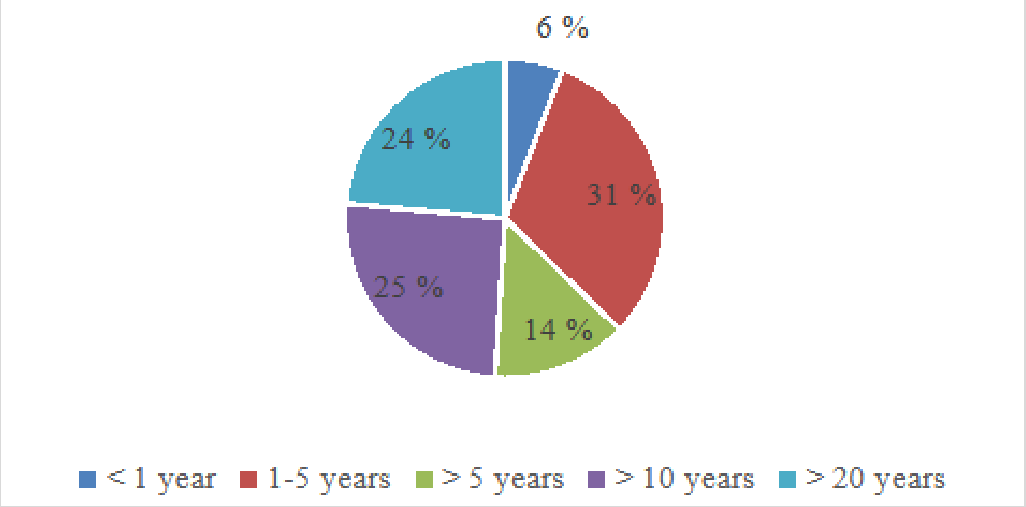
The Role of Artificial Intelligence (AI)

When asked, “What impact might AI have on the radiology specialty in the future?”, as many as 91.2% of respondents stated that AI would facilitate the work of radiologists. Other popular responses included: AI would reduce the likelihood of errors (76.5%), and AI would change the nature of radiologists’ work (41.2%).

4. PHYSICIAN’S OPINION ON THE RADIOLOGY SPECIALITY

The responses regarding work experience from the 51 radiologist physicians who participated in the study were evenly distributed (Fig. 3).

Fig. 3 Work experience of radiologist physicians.



74.5% of physicians stated that their work meets the expectations they had during their studies, indicating a high level of job satisfaction. Regarding interest in radiology, it most often began during their studies: 39.2% of physicians became interested during their first to fourth years of study, while 37.3% became interested during their fifth to sixth years. These data reveal that radiology attracts students at different stages of their studies. Moreover, compared to residents, physicians more frequently indicated that radiology is compatible with their personal life—49% chose the answer “yes,” while 43.1% stated that it is only partially compatible.

In the survey, physicians most frequently chose the answer “5 (very interesting)” when evaluating future prospects related to technological advancements. Additionally, statistically significant differences were observed between the views of men and women. Women valued the importance of human anatomy in radiology more highly (p=0.025) and more often than men indicated the desire to acquire new knowledge as an important aspect (p=0.034) (Table 2). When asked to select the five most important aspects for choosing radiology, 32 physicians (62.7%) noted that the specialty aligns with their personality, interests, and abilities, while 30 physicians (58.8%) identified salary potential as a significant factor. The least influential aspect was the duration of residency studies (Fig. 4).

The Role of Artificial Intelligence

Current developments in AI are particularly relevant to radiologists in clinical practice. For this reason, the study aimed to determine what impact AI, in physicians’ opinions, could have on this specialty. The vast majority, as many as 70.6%, chose the response that artificial intelligence would facilitate the work of radiologists, while 68.6% indicated that AI would reduce the likelihood of errors. Nearly half (49%) believe that AI will change the work of radiologists in the future. Despite the influence of AI and potential changes, as many as 80.4% of radiologists would recommend this specialty to future doctors, emphasizing a high level of satisfaction with the specialty.

Fig. 4. Importance of Interest Factors for Radiologist Physicians.

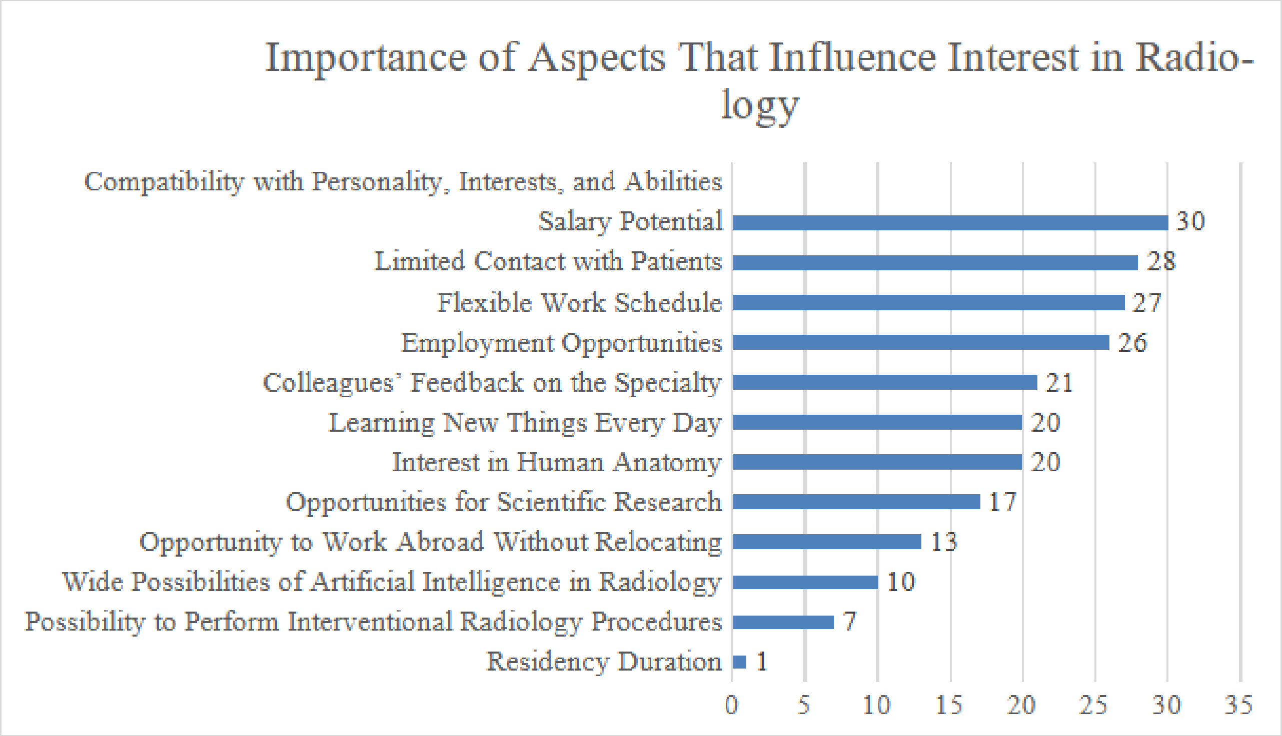


Table 2

Mean/Median	RESIDENTS(n=33)		PHYSICIANS (n=51)	
	Mean	Median	Mean	Median
1. Broad opportunities for subspecialization in various fields	4.03	4.00	3.43	4.00
2. Possibility to become an interventional radiology specialist	2.12	1.00	2.08	1.00
3. Variety of clinical cases	3.73	4.00	4.04	4.00
4. Interest in radiological image analysis, description, and interpretation	3.97	4.00	4.14	4.00
5. Interest in human anatomy	3.03	3.00	3.63	4.00
6. Opportunities for scientific research	2.64	3.00	3.57	4.00
7. Desire to acquire new knowledge	3.37	4.00	4.04	4.00
8. Compatibility with personality, interests, and abilities	3.64	4.00	3.75	4.00
9. Future prospects in technological advancements	3.76	4.00	4.25	5.00
10. Opportunities for artificial intelligence in radiology	3.24	3.00	3.50	4.00

5. KEY ASPECTS IN EVALUATING THE RADIOLOGY SPECIALITY BY GROUPS

Students most frequently indicated the importance of a flexible work schedule (56.1%), the opportunity to work in foreign hospitals (54.1%), and the possibility of remote work (53.1%). These aspects reflect students' priority on workplace and time flexibility, which may be associated with their desire to balance professional and personal life.

Resident doctors valued the possibility of remote work the most (55.9%), followed by the broad subspecialization opportunities in the specialty (47.1%), and the use of artificial intelligence to reduce the likelihood of errors (41.2%). This highlights resident‘s focus on technological innovations, practical work, and their desire to achieve high competence in the field of radiology while avoiding errors.

Physicians emphasized the alignment of personality, interests, and abilities with the radiology specialty (62.7%), salary potential (58.8%), and limited contact with patients (54.9%). These aspects underscore the influence of long-term professional experience on their evaluations, emphasizing the compatibility of their career with personal life.

6. CONCLUSIONS

Students value a flexible work schedule, opportunities to work remotely, or in foreign hospitals the most, emphasizing work mobility and flexibility. Resident doctors highlight the potential for technological advancements, subspecialization opportunities, and the benefits of artificial intelligence (AI) in reducing the likelihood of errors, reflecting their focus on innovation and practical experience. Physicians prioritize salary potential, limited patient contact, and the compatibility of the specialty with their personal characteristics, which reflects their long-term professional experience and need for stability. Although most respondents indicated that AI would facilitate radiologist‘s work and reduce the likelihood of errors, students were less likely to associate AI advancements with their career choices compared to residents and physicians.

7. RECOMMENDATIONS

The study results reveal that the radiology specialty offers a wide range of attractive aspects; however, there is a need to improve its presentation to students by emphasizing practical opportunities and technological advancements. Universities and residency programs are recommended to strengthen the image of the radiology specialty, particularly highlighting the importance of artificial intelligence and technological innovations. It is essential to promote practical training sessions and increase students' involvement in radiology activities to reduce the gap between theoretical knowledge and practical skills.

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Contrast-Enhanced Ultrasound in Interventional Procedures: a literature review

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ABSTRACT

Ultrasound is a popular diagnostic technique, commonly used in medical practice. It is an excellent tool for procedure guidance because it creates an opportunity for safe minimally invasive therapies, but its biggest drawback is the lack of enhancement information. UCAs enhance US images significantly, thus widening the possibilities of US imaging and making CEUS a valuable complementary technique. UCAs can help make the treatment more effective, lessen complications, and improve the success rate of interventional procedures.

Aim. The point of this article is to briefly summarise and present the importance of UCAs and the main types of promising CEUS-guided interventional procedures.

Methods. Research papers were selected from the computer bibliographic database PubMed.

Conclusion. CEUS makes differentiating body tissues easier without any adverse effects of more conventional diagnostic tools, improves the visual distinction of necrotic or vascularised areas, and the assessment of specific treatment response after many vascular, non-vascular, or even oncologic procedures. It is a convenient method for interventional procedures like biopsies, catheterizations, and ablations.

Abbreviations: CEUS – contrast-enhanced ultrasound, US – ultrasound, UCA – ultrasound contrast agent, MRI – magnetic resonance imaging, CT – computer tomography.

Keywords: *contrast-enhanced ultrasound, ultrasound contrast agent, interventional radiology, interventional procedures, ultrasound guidance.*

INTRODUCTION

Ultrasound is a popular diagnostic technique, commonly used in medical practice. Conventional grey-scale and colour Doppler modes of the US are critical parts of today's medicine and provide important information before and after treatment [1]. The US has a couple of well-known advantages: it produces images without radiation, it is accessible and available in basically every medical centre, and it's easily portable as well [2].

This diagnostic technique is an excellent tool for procedure guidance because it creates an opportunity for safe minimally invasive therapies, but its biggest drawback is the lack of enhancement information [2,3]. Ultrasound contrast agents enhance US images significantly, thus widening the possibilities of US imaging and making CEUS a valuable complementary technique [2,3]. There is more and more evidence every year that CEUS, a type of US combined with an intravenous contrast agent, is a trustworthy alternative to other more expensive imaging techniques, especially in the case of medical interventions such as biopsy, drainage, ablation, and others [2,3]. UCAs can help make the treatment more effective, lessen complications, and improve the success rate of interventional procedures [2]. CEUS makes differentiating body tissues easier without any adverse effects of more conventional diagnostic tools and improves the assessment of specific treatment response after many vascular, non-vascular, or even oncologic procedures [1,4].

CEUS TECHNIQUE

UCAs eliminate the issue of lack of enhancement with conventional US [3]. The most popular UCA in Europe and Asia that can be used to visualise the liver, breasts, or blood vessels is called SonoVue (Bracco; Milan, Italy). Meanwhile, Americans use different UCAs: Definity (Lantheus Medical Imaging; North Billerica, Mass), Optison (GE HealthCare; Princeton, NJ), and Lumason (Bracco Diagnostics; Monroe Township, NJ) [2].

UCAs consist of microbubbles, that have a low-solubility filling gas, for example, sulfur hexafluoride. The filling gas is stabilised by a phospholipidic shell (either lipid or albumin). The function of these microbubbles is to reflect US waves and act as acoustic enhancers [1,4]. This way harmonic signals can be easily detected by a US machine with special software. UCAs, injected into the bloodstream, can remain in the patient's organism for approximately 5 minutes. UCAs are specifically designed to be smaller than 7 µm to circulate freely in the bloodstream without diffusing into extravascular tissues [1,4]. After another 10 minutes, UCAs' gaseous content is safely exhaled through the lungs, while the phospholipidic shell is metabolised in the liver [2].

UCAs must only be prepared if they are about to be used [1]. After starting up the contrast agent software, UCAs are usually used intravenously as a bolus, administration is followed by 10 ml 0.9% normal saline flush [1–3]. The exact volume of needed UCAs is calculated individually based on the target structure, sensitivity of the US machine, and the type of UCA (generally the volume is 1.2-4.8 mL) [3]. It is important to note that the UCAs need to be injected slowly and carefully to prevent rupturing of the microbubbles. Intravenous use of UCAs makes them a great way to assess vascularity or perfusion, both on microvascular and macrovascular levels. This means CEUS can be performed to assess various vascular pathologies, and determine the location and characteristics of the abnormality. Moreover, CEUS delineates the endoluminal border, reduces echoes from tissues, furthermore improving the image quality [2]. Images created by UCAs' nonlinear signals can be visualised while disabling signals from background tissues, making them especially useful for visualising hardly seen lesions [1]. Finally, CEUS is perfect for monitoring changes in real-time, for instance, changes in the arterial phase. It enables monitoring the patient for a longer time, as there is no fear of radiation exposure [2]. It is recommended to perform a conventional US before CEUS because it is important to first identify the area of interest and consider a need for CEUS afterwards [3].

One of the advantages of UCAs is that they are better tolerated by patients than CT and MRI contrast agents, as they have fewer adverse effects. Most importantly, UCAs have no nephrotoxic effect as they are not excreted by the kidneys, so they can be safely used by patients who have nephrological pathologies [2,5]. CEUS has distinctive benefits: real-time target and needle imaging, lack of radiation, portability, and accessibility. Furthermore, no additional laboratory tests for renal function are required. It is important to be careful when using UCAs in patients who suffer from severe coronary artery disease or pulmonary hypertension. Unstable ischemic heart disease (that occurred in the last 7 days) and pregnancy are considered relative contraindications for CEUS [2].

However, there are a couple of drawbacks. It is difficult to perform CEUS if the patient is obese. Reduced image enhancement quality is seen if the patient is under general anaesthesia or intubated, requiring a higher dose of UCA or disabling the ventilation for a short time to get a good image quality. What is more, deeper structures like some parts of the spleen or liver may not be well-imaged, and rib shadows or respiration might disturb the image [2,3]. As in the regular US, the performance and results of CEUS crucially depend on the skill of the physician [2]. Adverse effects of CEUS are headache, chest pain, nausea, or anaphylactoid reactions, but they are rare. The main obstacle radiologist faces is poor visualisation of the needle itself during CEUS. According to studies, the visualisation of the needle can be improved by introducing air into the needle, using reference images, or contrast software of the machine to plan the needle path ahead of time [4].

CLINICAL APPLICATIONS OF CEUS FOR INTERVENTIONAL PROCEDURES

One of the most important indications of using CEUS is a biopsy. Probably the biggest issue of the conventional US is its poor ability to differentiate between the target organ and adjacent structures, leading to the unsuccessful interventional procedure [3,6]. This issue is most noticeable in the case of small lesions and masses deep in the abdominal area [6]. CEUS greatly enhances the visualisation of the target by improving contrast with nearby structures and helps determine the vascularisation of the tumour tissue, reflecting its viability and differentiation from surrounding parenchyma [2,3]. This diagnostic tool is also helpful in avoiding central necrosis areas when performing a biopsy [2]. The most popular instance of CEUS usage is liver biopsy. CEUS definitely improves biopsy planning and targeting of hepatic lesions while also helping the radiologist avoid necrotic areas and place the needle precisely [1,4]. Higher success rates, sensitivity, and specificity of lesions for liver biopsy compared to the conventional US have been noted by many different studies [1,4,5]. One of the studies found that most of the liver lesions showed much better conspicuity and accuracy on CEUS imaging. That means the CEUS can help prevent misdiagnosis and ensure that the patients will get the correct treatment [5]. CEUS can be used to perform different biopsies as well, for example, renal biopsy, prostate biopsy, or spleen biopsy [4]. We present a case from our clinical practice of CEUS-guided liver biopsy (Figs. 1–3).

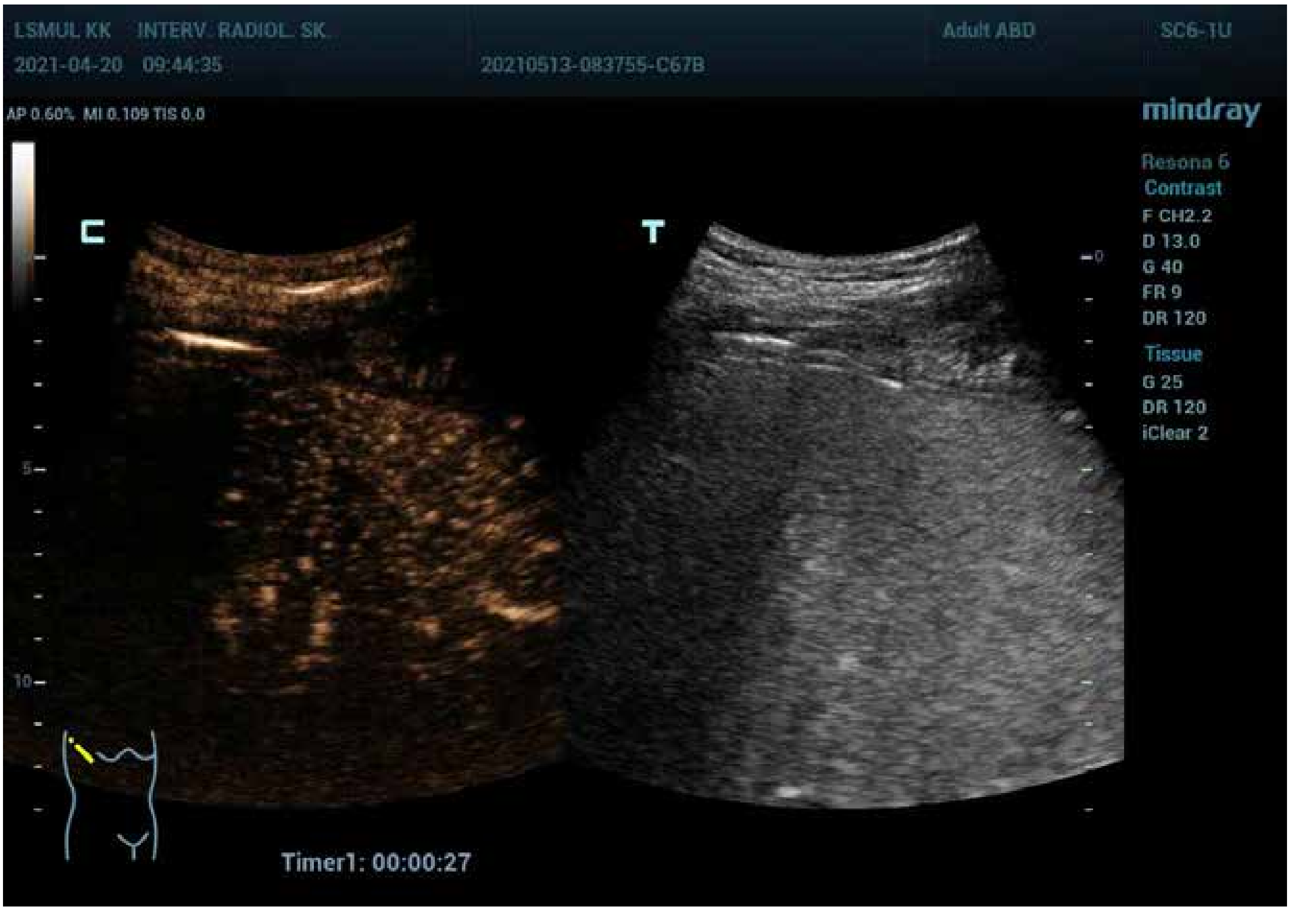
Figure 1. (A) US examination of the liver, simple B-mode. The red asterisk indicates a hyperechogenic nidus in the S7 segment (authors' archive). (B) Live video footage of the same US examination of the liver.

A

B

Figure 2. (A) US examination of the liver. On the right side – simple B-mode, on the left – CEUS with SonoVue, a cavity in the nidus is obvious (two asterisks), but it was not detected in the B-mode (one asterisk)(authors' archive). (B) Live video footage of the same US examination of the liver.

A



B

Figure 3. (A) US examination of the liver. On the right side – simple B-mode, and on the left – CEUS with SonoVue, a biopsy needle is evident (three asterisks). With the help of CEUS, it is possible to perform a biopsy from the surface of the nidus without entering the cavity (authors' archive). (B) Live video footage of the same US examination of the liver.

Abdominal abscess drainage is another common indication for using CEUS. Abscesses may have a variable appearance on the conventional US, sometimes making them challenging to identify [4]. Complex collections, such as liver abscesses, might appear mass-like or solid [3]. Meanwhile, during CEUS abscesses are characterised by mostly having irregular rim enhancement with nonenhanced nonvascular areas in the middle, which means the delineation of the target's boundary is improved [2,3]. CEUS is a great tool to execute percutaneous drainage, because this method improves the depiction of the avascular segments, making it easier to perform the puncture and place the drainage catheter in the optimal area, minimising the risk of unintentional puncture of surrounding organs [2,3]. Additionally, CEUS can be useful to determine if the catheter has drained all the cavities or has been placed incorrectly [2]. The biliary system or the pleural cavity can also be drained using CEUS. It is used to get insights about the catheter position or the level of obstruction because these factors can determine if the drainage is going to be successful [2,3]. CEUS is especially useful if the biliary system is non-dilated [3].

Another substantial procedure is nephrostomy. During this procedure, the calyx might be badly visible in the case of a non-dilated collecting system or case of blood clots or pus collected in the calyx [3]. CEUS noticeably increases the visibility of the calix by highlighting the caliceal system, which is non-vascularised [2,3]. It is possible to fill up the lumen of the needle with

UCA, increasing the visibility of the needle itself, and making it easier to navigate the needle. This way it is easy to instantly confirm the procedure when microbubbles reflex back to the needle or microbubbles are seen in the kidney [2,3]. If the UCA is administered by the drainage catheter, the upper and lower urinary tract becomes much better visualised [2]. Today, CEUS-guided nephrostomy is mainly used in difficult cases, in which radiation must be avoided, for instance, children, pregnant women, and patients who suffer from chronic kidney disease [4]. CEUS is especially suitable for those who are allergic to iodinated contrast material, used in CT scans [2].

In addition, CEUS is useful in ablation therapy as it helps to plan the treatment or evaluate the response after the procedure and determine the need for another ablation [2,3]. It enables a more accurate size assessment of the tumour and improved visibility of the target lesion, which might not be seen on a conventional grey-scale US [2,3,6]. CEUS is a great tool for ablation therapy because this procedure requires accurate placement of the probes and accurate delineation of the target. With the advancement in thermal ablation technology, ablation is now considered a perspective option in the case of abdominal tumour and its management. CEUS-guided ablation is usually used for liver or renal tumours to decrease their residual mass and lessen the number of treatment sessions [1,3].

CEUS is very effective for detecting portal vein thrombosis. According to several studies, CEUS has a higher sensitivity even compared to advanced diagnostic tools like MRI or CT. A biopsy of the portal vein thrombus is needed to diagnose a disease called occult hepatocellular carcinoma in cirrhotic patients. The thrombus biopsy might also be performed to evaluate the patient’s suitability for a liver transplant [4].

Last but not least, CEUS can be successfully used to perform cholangiography. During the procedure UCAs are injected through the catheter, enabling important information about the location of the tip or cavity evaluation. This diagnostic tool is useful for evaluating the biliary system, its ducts, obstruction, cysts, or leakage. Even though studies mostly consist of case reports, CEUS-guided cholangiography is reported to be an accessible and very useful tool, mostly performed in critically ill patients at the bedside or routinely as a follow-up test [4].

CONCLUSION

To sum up, CEUS considerably improves the visual distinction of necrotic or vascularised areas. This promising and quickly developing method combines the accessibility and safety of the conventional US with the advanced visualisation capabilities of UCAs [3,4]. By using this method, we prevent other imaging tools' radiation or nephrotoxic effects [2]. It is a convenient method for interventional procedures like biopsies, catheterizations, and ablations [4]. Even though the effectiveness of CEUS is well-documented, it is still important to promote this diagnostic tool to referring surgeons, nephrologists, urologists, and other specialists. Improvements in workflow and cooperation between physicians will incorporate this problem-solving imaging tool into daily practice [1,6].

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Medical Image Fusion: Clinical Applications and Future Development. A literature review

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ABSTRACT

Medical image fusion involves using multiple radiologic images of the desired region of the patient's body, co-displaying them both at once and creating a joint image. Because image fusion provides more accurate and precise data, the technique reduces overall operative time, complexity and risk of the operation itself. The fact that images of different scans can provide different information on the same anatomical parts of the body means image fusion is a perspective technology for various clinical fields, including oncology, cardiology and neurology.

Aim. The point of this article is to present medical image fusion, its history, technique, technical difficulties, clinical applications and future development.

Methods. Research papers were selected from the computer bibliographic database PubMed.

Conclusion. Image fusion can noticeably reduce the radiation dose for the patient and improve the outcome of the procedure. Though there are still a couple of drawbacks that are expected to be eliminated in the future advancements, even today image fusion is a powerful tool that in the hands of experienced radiologists can make complicated procedures like biopsy, aneurysm repair, carotid stenting, and endoleak embolisation safer, easier and faster.

Abbreviations: CT – *computed tomography, SPECT – single-photon emission computed tomography, PET – positron emission tomography, MRI – magnetic resonance imaging, T1 – longitudinal relaxation time, T2 – transverse relaxation time, US – ultrasound, CTA – computed tomography angiography, MRA – magnetic resonance angiography, 3D – three-dimensional, 2D – two-dimensional.*

Keywords: *medical image fusion, image fusion, fused image, joint image, image fusion-guided procedures, image fusion technique, future radiology.*

INTRODUCTION AND THE HISTORY

Medical image fusion is a vital tool in radiology that enables the integration of all the information of different modalities and helps to create an accurate diagnosis. The term itself covers a wide range of aspects including machine learning, artificial intelligence or pattern recognition. Image fusion can noticeably reduce the radiation dose for the patient and improve the outcome of the procedure. [1]

The term "image fusion" was first seen in 1985 and completely changed the military, physics and medical fields. The latter field greatly benefits from such technology, because images of single scans provide minimal information in specific areas of diagnostic medicine. [2]

Supposedly the first image fusion ever performed was a CT-SPECT scan performed by Swayne in 1992. Images were fused using mostly anatomical landmarks by rotating and stretching them. The technology has been rapidly improving and has since been used mostly by neurosurgeons and oncologists. [1] Since 2012 image fusion has seen major advancement and has become a hot topic among physicians. It is possible to fuse many different types of scan images, however, the most common types of image fusion are MRI-PET, MRI-CT, MRI-SPECT, CT-PET, CT-SPECT, SPECT-PET, MRI-T1, MRI-T2 fusion. Different types of images provide different useful information for the radiologist. [2]

TECHNIQUE AND ADVANTAGES

The process involves using multiple images of the desired region of the patient's body, co-displaying them both at once and creating an individually joint image. This results in a more precise picture, making it easier to make an accurate diagnosis. The main goal of this is to create a useful and more informative fused image and ensure better clarity and lack of any distortion. [2–4]

Images of different scans can provide different information on the same anatomical parts of the body. This is due to the different sensors of the scan machines that make those images become reality. If we fuse different kinds of images (so-called multimodal fusion), we get better contrast, quality and perceived experience. [2]

The goal of creating a fused image can be achieved using different methods. Some say that multi-resolution analysis is the most useful technique for creating fused images and can produce pictures that have noticeably higher resolution. Others argue that dividing input images into separate blocks ensures a smoother fused image. Furthermore, multimodal images can be combined on different levels, thus leading to a higher number of combinations available. The technique could be useful in operative analysis and accurate diagnosis. Wavelet transformation technique can be used to merge edges and boundaries of a primary image, this method provides better contrast and image details. [3] As a matter of fact, the modern type of technique that makes image fusion a reality is called the transform domain. It converts the image to the frequency domain, fuses it with another image and finally reconstructs them both. Transform domain type of image fusion usually provides good structure and helps to avoid distortion in the final picture, but can generate noise, which disrupts the final result. [2]

Image fusion is a complex process that combines several steps. The first step is segmentation. During segmentation, preferably CT images are used to create a 3D model of anatomical structures. The physician selects the specific anatomical parts to be included in the final image model. Those parts need to be verified on axial images. After segmentation has been completed, a 3D model is ready to be used for operation planning and various markers are placed on top of the picture. [5]

The second and most important step in image fusion is registration – a process during which the inputs are mapped using a referenced image. Therefore, the purpose of image registration is to align images accurately with each other as it enables the creation of a new single fused image out of two different ones. [3,4] Two images are used for this: one image is called the referenced image; the second image is called the sensed image. Unimodular registration uses images acquired by a similar device, meanwhile multimodular registration uses images acquired by various devices. [3] It is crucial to align one image with another correctly. The process can be done manually by a physician using anatomical landmarks, for instance, umbilicus, nipples, and vertebral column, or automatically by artificial intelligence using individual pixels. [1,4,6] If the registration is rigid, the physician is only allowed to drag or rotate the images, but if the registration is deformable, stretching becomes available as well, which is necessary for aligning the anatomical landmarks. [7] Though this work today is mostly done manually, one trial has demonstrated that automated image fusion is accurate and only differs 0,1 mm from manual fusion. The difference is tiny and does not hold any clinical value. [6]

Nevertheless, these image-guided procedures require additional tools that enable navigation during the procedure. Navigation tools are capable of importing the database of acquired images, co-displaying them with real-time images and tracking minimally invasive instruments. Electromagnetic and optical tracking and cone beam CT-based tracking are the most commonly used ones. Optical tracking is considered the most accurate one, but it suffers from line-of-sight requirement that limits the use of this navigation tool. Line of sight phenomenon requires that there is always a direct unobstructed pathway between the minimally invasive instrument and the camera. [7]

There are many advantages to image fusion. First of all, it greatly reduces the amount of radiation exposure. Some sources claim the radiation is decreased by 2000 mGy, although it depends on the type of the procedure. This result is significant because these patients often require follow-up high radiation dose scans, such as CT scans. Decreased radiation also helps to protect the practitioners who perform these procedures every single day. To add, image fusion enables less contrast medium to be used during the interventional procedure. According to meta-analysis, patients require upwards to 70.7 mL less iodinated contrast medium during complex aortic procedures. In case of kidney failure, it is possible to undergo an operation without any contrast medium at all. Because image fusion provides accurate data, another benefit is reduced overall operative time, complexity and risk of the operation itself. [4,5,7]

However, there are some drawbacks. The technical difficulty is the need to fuse both images manually because most software is still not able to merge images fully automatically. [6] The physician must ensure that the steps performed by the software are without errors. The capabilities of this technique are limited based on the software that requires up-to-date machines to integrate all the latest advancement technologies. Another concern is that 3D models are created before the operation and the general view of the patient's anatomy might be different during the operation because of the introduction of endovascular devices or patient movement (there might be upward to 7 mm difference). It is important to remember that this advanced technology still requires manual corrections by the physician. [5,7] Furthermore, medical images tend to vary a lot as there is heterogenicity in body parts and organs. That is the reason why it is difficult to perform image fusion by excluding specific body structures and then merging them. [3,7] Finally, many researchers still discuss and cannot decide what is the best fusion method. The methods are often modified and tested in clinical practice. [8]

CLINICAL APPLICATIONS

Different types of images can provide different information for certain diseases and pathologies. MRI-PET fusion images are great for detecting liver metastasis and brain tumours. Moreover, CT-PET fused images are valuable for diagnosing lung cancer. [2] MRI-PET image is an essential part of making a diagnosis of Alzheimer's disease. It is also helpful in diagnosing cancer and is bound to become an important part of clinical oncology. [2] Meanwhile, the strong suit of MRI-SPECT fusion images is detecting lesions and metastasis of vertebral bone. MRI-SPECT fusion image is actually different from already discussed ones as it provides both structural and functional information. [2]

Echocardiograph-X-ray fusion enables merging transesophageal echocardiography images onto a fluoroscopic screen. Merged image is great to use for several different interventions, including transseptal puncture, aortic valve replacement, mitral valve repair or valvuloplasty. The technique is advantageous in the case of percutaneous procedures, but it is still a question of time once scientists discover another "niche" application for this type of fusion. [9] Angiography-SPECT fusion shows the relationship between coronary vessels and myocardial ischemia. Angiography-US fusion has helped to precisely depict the anatomy of the vessels and their relationship with adjacent structures. CTA-MRI fusion is essential for localising coronary arterial stenosis and the defects of myocardial perfusion. MRI-X-ray fusion is vital for the transendocardial delivery of stem cells because it visualises the infarct zone in a three-dimensional view. MRI-CT images can help guide atrial fibrillation. The fusion of MRI-fluoroscopy or CT-fluoroscopy is being used for congenital heart disease catheterization with good results. [1]

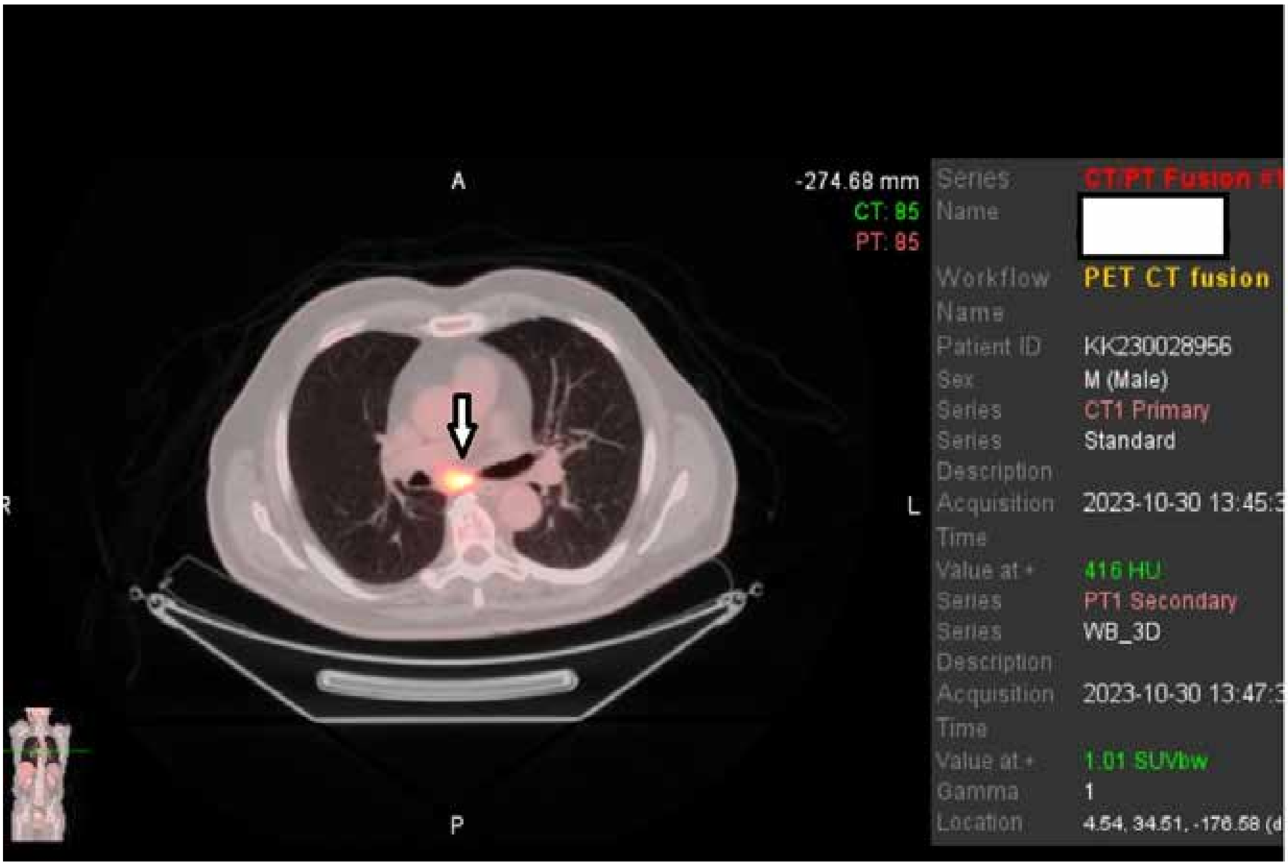
Image fusion is also used for endovascular procedures. More specifically, during stent-graft deployment for an aneurysm, a CTA or MRA image is used as a base map while live fluoroscopy is overlaid on top. Clinically this technique has shown positive results as it made complex procedures easier. Image fusion can be used in even more challenging situations like closure of an atrial septal defect, shunt procedures or catheterization of a graft. [6,7] In these cases, a CT image is used as a map of the landmarks and is overlaid with an angiography image. [7] Moreover, it is now possible to create a three-dimensional map of the patient's vessels and merge it with fluoroscopy. The CT image is used as a three-dimensional base image, which is then used to schedule the procedure. [5]

Image fusion improves the precision during endovascular aneurysm repair. The accurate fused model is so effective that a fenestrated device can be introduced without a contrast medium. What is more, an aortogram might not be required for image confirmation, if the vessels are cannulated without any difficulties. Thoracic endovascular aneurysm repair also benefits from image fusion, because it ensures less catheter manipulation and helps visualise the proximal end of the graft. However, in this case, image fusion is less reliable because of calcification of the vessels and patient movement. [5]

Physicians already utilise image fusion to give them an advantage when dealing with endoleaks. The fused image is a valuable tool that provides detailed anatomical guidance for various types of endoleaks. The technique ensures precise placement of the proximal or fenestrated cuff and is crucial for endoleak embolization. Translumbar and transcaval endoleak embolization demand an extremely precise approach to avoid damaging adjacent structures. [5]

Image-guided interventional procedures are essential parts of modern medical oncology. [4,7] Percutaneous thermal ablation is getting increasingly popular because of its important role in cancer treatment. With the help of image fusion performing thermal ablation, targeting specific tissues, administering the correct drugs and choosing the correct personalised therapies is more precise. Image fusion is also noticeably useful in performing organ biopsies. Organ biopsy is an essential part of tumour diagnosis and can help identify the malignant disease, its subtype and specific identification. [4]

Figure 1. CT-PET fused image. Low-dose CT scan was merged with PET scan to visualise the site of radiopharmaceutical (marked with an arrow).



Series CT/PT Fusion #1
Name [redacted]
Workflow Name PET CT fusion
Patient ID KK230028956
Sex M (Male)
Series CT1 Primary
Series Description Standard
Acquisition Time 2023-10-30 13:45:3
Value at + 416 HU
Series PT1 Secondary
Series Description WB_3D
Acquisition Time 2023-10-30 13:47:3
Value at + 1.01 SUVbw
Gamma 1
Location 4.54, 34.51, -176.58 (d

CONCLUSION AND FUTURE DEVELOPMENT

All in all, image fusion is a complicated process, various parameters such as scale, orientation, resolution and evaluation algorithms are important criteria to obtain a good fused image. [8] The process requires experience and knowledge of anatomy, physics and other scientific fields.

Image fusion has been a hot topic for the past 8 years and has been a part of clinical trials for biopsies, ablations and visualisation of drug effects

Figure 2. CT-PET fused image. Abnormal metabolically active sites are marked with arrows.

or biomarkers. This technique reduces the radiation and contrast medium dose. What is more, image fusion reduces complication rates and increases the success rate of certain procedures. [7] Image fusion is mostly beneficial in the following procedures: biopsy, aneurysm repair, carotid stenting, and endoleak embolisation. [5]

The fusion of the pictures should be improved in the future. [3] Physicians expect image fusion to become a tool being used daily. Registration and output of image fusion will become faster and more in-depth. [7] Future development of image fusion should focus on implementing artificial intelligence and fully automating the process of registration. [6] It is probably possible to create precise software that will require no manual input from the physician. Physicians are hoping that in the future the software will be able to determine and eliminate the errors caused by patient movement or the introduction of endovascular devices. The software should predict and address the deformations of the vessels before the operation. [5]

On the other hand, different researchers tend to use different kinds of evaluation indicators. A consensus needs to be made as the current situation leaves a lot of room for different interpretations and causes confusion or different results. [2] Hopefully, this will be solved eventually and image fusion will become a gold standard in various medical fields.

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