Radiological Evaluation of Acute Chest Pain: A Review of Diagnostic Imaging Strategies

Nawaf Alraydh K Alshammari [1], Fayez Huri Munnawer Alanazi [2], Faisal Basam Alsalal [3], Waleed Abdulrahman Ibrahim Aloudah [4], Falah Fares Alenezi [5], Almutairi Rayid Tuwayli M [6], Hejab Khatam Alrawili [7], Faisal Daham Alodhaylah [8], Salem Sufuq Mohammad Alenazi [9], Alghaythi, Ayad Talal M [10]

1- Technician-Radiologic Technology, Rafha Central Hospital, Saudi Arabia
2- Radiological Technology, Eradah Complex for Mental Health, Arar, Saudi Arabia
3- technician-radiologic technology, Eradah Complex for Mental Health, Arar, Saudi Arabia
4- technician-radiologic technology, Northern borders health cluster, Saudi Arabia
5- technician-radiological, Convalescence and Extensive Care Hospital, Arar, Saudi Arabia
6- technician-radiologic technology, Ministry of Health Branch- Al Madinah, Saudi Arabia
7- technician-radiologic technology, Medical rehabilitation and Care Hospital, Arar, Saudi Arabia
8- X-ray technician, Ministry of Health Branch- Northern Border Region, Saudi Arabia
9- technician-radiologic technology, Ministry of Health Branch- Northern Border Region, Saudi Arabia
10- technician-radiologic technology, Turbah Healthcare Center, Hail, Saudi Arabia

Abstract:

Acute chest pain is a common clinical presentation that necessitates prompt and accurate diagnosis to differentiate between life-threatening conditions, such as myocardial infarction and pulmonary embolism, and less severe causes. The role of radiological evaluation in this context is critical. Various imaging modalities, including chest radiography, computed tomography (CT), and magnetic resonance imaging (MRI), have unique advantages in assessing structural abnormalities, vascular pathology, and pulmonary conditions. Chest X-rays remain the first-line imaging tool for ruling out pneumonia and pleural effusions, while CT angiography has become increasingly important for rapid assessment of coronary artery disease and aortic dissections. Consequently, the selection of the appropriate imaging strategy depends on the clinical context, the patient's presentation, and the urgency of diagnosis. Key considerations in the radiological evaluation of acute chest pain involve the balance between diagnostic accuracy, speed of imaging, and radiation exposure. While CT plays a pivotal role in quickly identifying critical conditions, its use must be judicious to minimize unnecessary radiation, especially in younger patients. MRI, though less commonly used in acute settings due to availability and longer acquisition times, offers excellent soft tissue characterization and can provide crucial information in cases of myocarditis or pericardial diseases. Overall, a systematic approach to radiological evaluation, integrating patient history, clinical examination, and appropriate imaging modalities, is essential for effective management of acute chest pain.

Keywords: Acute chest pain, radiological evaluation, diagnostic imaging, chest X-ray, computed tomography, CT angiography, magnetic resonance imaging, myocardial infarction, pulmonary embolism, imaging strategies, clinical presentation, radiation exposure, myocardial diseases.

Introduction:

Acute chest pain is a common clinical symptom encountered in emergency departments worldwide. It poses a significant challenge for healthcare professionals, given its association with life-threatening conditions, including myocardial infarction, pulmonary embolism, aortic dissection, and pneumonia, among others. The diverse etiologies of acute chest pain necessitate an efficient and accurate diagnostic approach to identify the underlying cause and initiate appropriate treatment. In this context, radiological evaluation plays a pivotal role, serving as an essential tool in the emergency setting to streamline the diagnostic process and improve patient outcomes [1].

The primary goal of this research introduction is to explore the various diagnostic imaging strategies utilized in evaluating acute chest pain, focusing on their respective roles, advantages, limitations, and emerging technologies. The necessity for an effective diagnostic pathway is underscored by studies indicating that the misdiagnosis of acute chest pain can lead to catastrophic consequences, including increased morbidity, unnecessary interventions, and repeated hospitalizations. As a result, radiological assessment must not only be accurate but also timely and cost-effective [1].

The evaluation of acute chest pain typically relies on a combination of clinical assessment, laboratory tests, and non-invasive and invasive imaging modalities. Various imaging techniques provide critical insights into the anatomical, functional, and pathological aspects of the thoracic structures. Traditional imaging modalities, such as chest radiography and computed tomography (CT), have long been mainstays in the evaluation of acute chest pain. However, the advent of advanced imaging technologies, such as magnetic resonance imaging (MRI) and cardiac imaging, has further expanded the diagnostic arsenal available to clinicians [2].

Due to the heterogeneous nature of chest pain with different underlying etiologies, it is imperative to develop a systematic approach to radiological evaluation. This begins with a thorough clinical assessment, incorporating medical history, physical examination, and initial laboratory tests. Following this, imaging studies are often tailored according to the patient's presentation, risk factors, and clinical suspicion [3].

1. **Chest X-ray**: Despite being one of the oldest imaging techniques, chest X-rays remain a valuable first-line investigation in the emergency evaluation of acute chest pain. This imaging modality can identify major thoracic pathologies such as pneumonia, pleural effusions, and cardiomegaly, which may contribute to the patient's symptoms. However, chest X-rays possess limitations regarding sensitivity and specificity, as they may miss conditions like pulmonary embolism or aortic dissection [4].
2. **Computed Tomography (CT)**: Multidetector CT (MDCT) angiography has revolutionized the diagnostic landscape in emergency medicine. Particularly in the assessment of pulmonary embolism and aortic dissection, CT can provide rapid, high-resolution images of the thoracic vasculature and surrounding structures. The high sensitivity and specificity make MDCT an invaluable tool, although concerns persist regarding radiation exposure and the potential for contrast-induced nephropathy [4].
3. **Magnetic Resonance Imaging (MRI)**: MRI is increasingly utilized in the evaluation of acute chest pain, particularly in younger patients and those requiring repeat assessments without radiation exposure. While MRI is not typically the first-line imaging study in acute chest pain scenarios, it excels in characterizing soft tissue, assessing cardiac function, and evaluating myocardial ischemia. Nevertheless, challenges related to availability, cost, and longer acquisition times can limit its immediate application [5].
4. **Echocardiography**: As a non-invasive bedside tool, echocardiography plays a critical role in evaluating chest pain, particularly in cases involving suspected cardiac etiology. It is particularly useful for identifying abnormal wall motion, valvular heart disease, and pericardial effusion. The real-time capabilities of echocardiography can facilitate rapid decision-making, although operator dependency and limited visualization of the lungs may pose challenges [6].

Emerging Trends and Challenges

The field of radiological evaluation of acute chest pain is continuously evolving, influenced by advances in imaging technology, artificial intelligence, and machine learning. Emerging methodologies, such as dual-energy CT and advanced perfusion imaging, offer promising avenues for future research and application, potentially enhancing the diagnostic yield and expediting treatment pathways. Furthermore, the integration of clinical decision-support systems with imaging modalities can reduce unnecessary tests, thereby optimizing resource utilization [6].

Despite the advancements in imaging strategies, challenges persist, particularly concerning the interpretation of imaging findings and the need for a consensus on diagnostic protocols. As the medical community grapples with the increasing complexity of acute chest pain presentations, the establishment of standard guidelines and collaborative interdisciplinary approaches will be vital in ensuring accurate evaluations and optimal management strategies [7].

Overview of Diagnostic Imaging Modalities in Acute Chest Pain:

Acute chest pain is a common symptom that prompts patients to seek emergency care, often presenting a diagnostic challenge to healthcare providers. The differential diagnosis for acute chest pain includes a wide array of conditions ranging from benign to life-threatening, including myocardial infarction (heart attack), pulmonary embolism, aortic dissection, pneumonia, and musculoskeletal pain. Accurate and timely diagnosis is crucial to ensure appropriate management and improve patient outcomes. Among the various tools available, diagnostic imaging modalities play a pivotal role in the assessment of acute chest pain [8].

1. Chest X-Ray (CXR)

The chest X-ray is often the first imaging modality employed in the evaluation of acute chest pain. It is a readily available, cost-effective, and non-invasive test that provides a quick overview of the thoracic cavity. An X-ray can reveal various abnormalities such as cardiomegaly, pneumonia, pulmonary edema, and pleural effusions, as well as signs of aortic dissection.

Advantages

- **Rapid Execution**: A chest X-ray can be performed in a matter of minutes.
- **Low Radiation Dose**: The radiation exposure is minimal compared to more advanced imaging modalities.
- **Initial Evaluation**: It provides a general assessment that can guide further diagnostic testing.

Limitations
However, the limitations of chest X-rays must be recognized. They often fail to identify subtle pathologies, particularly in cases of myocardial ischemia or small lung emboli. Diagnosis might rely heavily on clinical correlation, and negative results do not rule out serious conditions like aortic dissection or pulmonary embolism [9].

2. Computed Tomography (CT)
CT angiography has emerged as a critical tool in the evaluation of acute chest pain, particularly for ruling out pulmonary embolism and assessing coronary artery disease. The technique uses intravenous contrast material to visualize the blood vessels in the chest [10].

Advantages

- **High Sensitivity and Specificity**: CTA has high sensitivity for detecting pulmonary embolism and coronary artery blockages.
- **Rapid Results**: CTA can be completed swiftly, often within 30 minutes, aiding in the prompt management of critically ill patients.
- **Comprehensive Evaluation**: Besides vascular assessment, CTA allows evaluation of other structures like the lungs, mediastinum, and thoracic aorta.

Limitations
Despite its advantages, CTA is not without limitations. The use of contrast agents poses risks of allergic reactions and nephrotoxicity, particularly in patients with pre-existing kidney impairment. Additionally, the high radiation exposure associated with CT scans is a concern, especially when multiple scans may be required [11].

3. Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) is another imaging modality that is used less frequently but possesses certain advantages for specific scenarios. Although it is not typically first-line in the evaluation of acute chest pain due to longer acquisition times and limited availability, it can be invaluable in assessing structural heart disease, particularly in patients with suspected myocarditis or aortic dissection [12].

Advantages

- **No Ionizing Radiation**: MRI does not expose patients to radiation, making it safer for certain populations.
- **Excellent Soft-Tissue Contrast**: MRI provides superior imaging of soft tissues compared to CT, which allows for detailed assessment of cardiac structures.

Limitations
Nevertheless, MRI's limitations include longer scan times and increased costs, alongside contraindications in patients with certain implants or devices (e.g., pacemakers). Furthermore, its availability may be limited in some emergency settings, delaying diagnosis when time is critical [12].

4. Echocardiography

Echocardiography, particularly transthoracic echocardiography (TTE), is a useful imaging modality in patients presenting with acute chest pain, especially in the evaluation of cardiac causes. It can swiftly assess ventricular function, valve function, and underlying structural abnormalities [13].

Advantages

- **Real-Time Imaging**: Echocardiography provides real-time imaging and assessment of cardiac function.
- **Bedside Availability**: It can often be performed at the bedside, facilitating immediate evaluation in emergency settings.
- **No Radiation Exposure**: Like MRI, it does not involve ionizing radiation, making it safe, particularly for vulnerable populations such as pregnant women.

Limitations
However, the limitations of echocardiography include operator dependency and difficulty in providing clear images in the presence of obesity or chronic lung disease. Its utility may also be constrained in cases where a detailed structural assessment is necessary, where advanced imaging techniques like CT or MRI may be more appropriate [13].

5. Single Photon Emission Computed Tomography (SPECT)

SPECT imaging can be beneficial in evaluating myocardial perfusion and stress testing for coronary artery disease in patients with atypical presentations of acute chest pain [14].

Advantages

- **Functional Assessment**: It provides information on blood flow and can be used for risk stratification.
- **Consideration for Ischemia**: SPECT is useful for identifying areas of the heart that are ischemic under stress conditions.

Limitations
However, SPECT scans have limitations such as lower resolution compared to CT and MRI and the need for radiopharmaceutical agents, which may pose risks to certain patients. It is not typically considered in the immediate assessment of acute chest pain unless other modalities are inconclusive [14].

Chest Radiography: First-Line Imaging in Acute Evaluation:

Chest radiography, commonly known as a chest X-ray, has long been regarded as the gold standard for initial imaging in the acute evaluation of various thoracic pathologies. The prominence of chest radiography in clinical practice is grounded in its accessibility, rapid execution, cost-effectiveness, and ability to provide crucial diagnostic information [15].

The advent of radiographic imaging dates back to the late 19th century, with Wilhelm Conrad Röntgen’s discovery of X-rays in 1895. Since then, chest radiography has evolved significantly, with advancements in technology leading to digital imaging, improved resolution, and enhanced diagnostic capabilities. Traditional film-based imaging has now transitioned to digital radiography, allowing for faster image acquisition, manipulation, and storage. Despite the influx of advanced imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI), chest radiography remains a cornerstone in the acute evaluation of patients presenting with respiratory symptoms, chest pain, or trauma [16].

Chest radiography is commonly indicated in a variety of clinical scenarios. In acute settings, physicians often rely on chest X-rays to evaluate conditions such as pneumonia, heart failure, pulmonary embolism, pneumothorax, and mediastinal pathology. The ability to quickly assess the lung fields for infiltrates, the heart size, and other thoracic structures makes radiography an indispensable tool for triaging patients [17].

In the context of respiratory infections, chest radiography plays a pivotal role in differentiating between bacterial and viral pneumonia. For patients presenting with cough, fever, and dyspnea, a chest X-ray can reveal the presence of lobar consolidations or interstitial patterns that indicate pneumonia. Furthermore, in suspected cases of heart failure, the chest X-ray assists in assessing cardiomegaly, pulmonary congestion, and pleural effusions, thus guiding immediate management strategies [18].

In trauma situations, particularly in patients who have experienced blunt or penetrating chest injuries, chest radiography serves as a rapid assessment tool to identify life-threatening conditions such as pneumothorax, hemothorax, and rib fractures. The ability to obtain immediate images allows clinicians to initiate timely interventions, which can be life-saving [19].

The advantages of chest radiography as a first-line imaging modality are numerous. Firstly, it is a rapid and straightforward procedure that can often be performed at the bedside, reducing the need for patient transport and minimizing delays in diagnosis. This is particularly beneficial in emergency settings where time is of the essence [19].

Secondly, chest radiography is cost-effective, making it accessible in a variety of healthcare settings. Its relatively low cost facilitates widespread use in emergency departments and outpatient clinics, thus ensuring that patients receive timely evaluations without significant financial burdens [20].

Furthermore, the radiation dose associated with a chest X-ray is minimal compared to that of advanced imaging modalities such as CT scans. This is particularly relevant in populations requiring frequent imaging, such as patients with chronic respiratory diseases or those undergoing surveillance for malignancies [20].

Another key advantage is the ability to provide immediate results, allowing clinicians to make informed decisions regarding further management or the necessity for additional imaging. This rapid turnaround can be crucial in critically ill patients or those with serious conditions requiring swift intervention [21].

Despite its many advantages, chest radiography has limitations that must be acknowledged. The sensitivity of chest X-rays can be hindered by factors such as the presence of overlapping structures, obesity, and suboptimal positioning. Small pulmonary nodules or early-stage diseases may not be easily identifiable, sometimes leading to missed diagnoses and delayed treatment [22].

Moreover, chest radiography provides limited information about soft tissue structures and is not as effective at evaluating certain conditions compared to advanced imaging techniques. For example, while radiography can detect pleural effusions, it may not provide detailed information regarding the underlying causes or the nature of the effusion without follow-up imaging, such as ultrasound or CT [23].

Interpretation of chest X-rays is also highly dependent on the clinician's experience, and there is an inherent variability in how radiographs are read. This subjectivity can lead to discrepancies in diagnosis, underscoring the necessity of radiological expertise in acute settings [24].

In recent years, the role of advanced imaging techniques such as CT and MRI has expanded significantly, often complementing chest radiography in the acute evaluation. While CT scans provide detailed cross-sectional images and are superior in assessing complex thoracic pathologies, they come with higher costs and increased radiation exposure. As a result, the decision to proceed with advanced imaging is often guided by the information gleaned from initial chest X-rays [25].

It is worth noting that the integration of machine learning and artificial intelligence (AI) into radiology is poised to enhance the interpretative accuracy of chest X-rays. AI algorithms can assist in detecting abnormalities that may be subtle and help in standardizing interpretations across different practitioners. This technological advancement further solidifies the role of chest radiography as a vital first step in the acute evaluation of chest-related conditions [25].

Computed Tomography: Benefits and Indications in Chest Pain Diagnosis:

Chest pain is a common clinical symptom encountered in emergency departments, outpatient clinics, and primary care settings, posing significant challenges for healthcare providers. The differential diagnosis for chest pain is vast, ranging from benign causes such as musculoskeletal pain to life-threatening conditions like myocardial infarctions or pulmonary embolisms. Among various imaging modalities available for the evaluation of chest pain, Computed Tomography (CT) has emerged as a vital tool in both diagnosis and management [26].

Computed Tomography is a non-invasive imaging technique that uses X-rays and computer technology to create detailed cross-sectional images of body structures. The modality enhances visualization of internal organs, soft tissues, and blood vessels, providing critical information that is essential for accurate diagnosis. Unlike traditional X-rays, which offer limited detail, CT scans can produce high-resolution images that help clinicians differentiate between various pathologies [26].

1. **High Diagnostic Accuracy**: One of the paramount benefits of CT in chest pain diagnosis is its high degree of sensitivity and specificity. When evaluating chest pain, especially in cases where acute coronary syndrome or pulmonary embolism is suspected, CT can provide rapid and reliable results that may impact patient management decisively. Studies have demonstrated that CT angiography, specifically, can accurately identify coronary artery abnormalities with a high negative predictive value, reducing the need for unnecessary invasive procedures like cardiac catheterization [27].

2. **Rapid Evaluation**: In acute settings, time is of the essence. CT can produce detailed results quickly, often within minutes. This efficiency is especially crucial in emergency departments where rapid decision-making can affect patient outcomes. For decisions involving anticoagulation therapy for suspected pulmonary embolism or immediate interventions in cases of aortic dissection, the speed of CT imaging can be life-saving [27].

3. **Multi-Organ Assessment**: A CT scan evaluates not only the cardiovascular system but also other thoracic structures. This capability allows clinicians to assess potential non-cardiac causes of chest pain, such as pneumonia, pleural effusion, and thoracic aortic aneurysms. By identifying alternative etiologies, CT can assist in guiding comprehensive management strategies while facilitating appropriate referrals [28].

4. **Non-invasive Nature**: CT is a non-invasive technique that typically requires no sedation, making it a suitable option for patients who may be at higher risk for complications from invasive procedures. This characteristic is particularly beneficial for patients who may have multiple co-morbidities or those who are in fragile health [29].

5. **Advancements in Technology**: With the ongoing advancement of CT technologies, including dual-energy CT and iterative reconstruction algorithms, image quality and diagnostic capabilities are rapidly improving. These innovations not only enhance the ability to detect subtle abnormalities but also reduce the radiation dose to patients, addressing a longstanding concern regarding the safety of imaging studies [30].

Indications for CT in Chest Pain

While computed tomography serves various functions in medical imaging, specific clinical indications warrant its use in the assessment of chest pain.

1. **Suspected Pulmonary Embolism**: When patients present with chest pain accompanied by symptoms such as dyspnea or hemoptysis, CT pulmonary angiography becomes the gold standard for diagnosing pulmonary embolism. The imaging modality allows for the visualization of blood flow through the pulmonary arteries, and a negative result is often sufficient to rule out this life-threatening condition [31].

2. **Acute Coronary Syndrome**: In cases where chest pain is suggestive of unstable angina or myocardial infarction, coronary CT angiography can be employed. This technique allows for the detection of coronary artery stenosis or occlusions, thus aiding in the management of acute coronary events [32].

3. **Investigating Aortic Dissection**: CT is paramount in cases where aortic dissection is suspected due to acute, severe chest pain often described as a tearing sensation. Rapid diagnosis using CT allows for timely intervention, significantly affecting morbidity and mortality associated with the condition [32].

4. **Evaluation of Pericardial Disease**: CT is also useful in assessing pericardial effusion or constrictive pericarditis, which can present as chest pain, especially in patients with underlying inflammatory or infectious conditions.

5. **Non-Cardiac Causes**: CT scans can play a pivotal role in identifying alternative diagnoses for chest pain, such as pneumothorax, pulmonary infections, or even gastrointestinal causes such as esophageal rupture. Identifying these non-cardiac pathologies helps to prevent misdiagnosis and ensures appropriate management [32].

Magnetic Resonance Imaging: Role and Applications in Acute Chest Pain:

Magnetic Resonance Imaging (MRI) is a non-invasive diagnostic tool that employs powerful magnets and radio waves to generate detailed images of the organs and tissues within the body. While traditionally associated with imaging the brain and musculoskeletal system, MRI has emerged as a significant player in evaluating acute chest pain, a critical symptom that can indicate a wide range of conditions, from benign musculoskeletal issues to life-threatening cardiovascular events. Given the complexity of chest pain diagnostics, the multifaceted role of MRI—and its applications in this context—warrants thorough exploration [33].

Acute chest pain is a symptom that can arise from numerous causes, including but not limited to coronary artery disease, pulmonary embolism, aortic dissection, pneumonia, gastroesophageal reflux disease (GERD), and musculoskeletal disorders. Given this broad differential diagnosis, effective initial assessment is pivotal for timely interventions. Standard imaging modalities such as X-rays, computed tomography (CT), and echocardiography have been the mainstay in acute settings, but these technologies come with limitations concerning sensitivity, specificity, and exposure to radiation [34].

Traditionally, MRI has not been as widely adopted for acute diagnostic applications primarily due to factors such as accessibility, cost, and the presence of contraindications (e.g., metallic implants). However, advancements in MRI technology, such as faster acquisition times and improved magnet strength, have begun to address these limitations. MRI can provide exquisite soft tissue contrast and is particularly adept at identifying conditions involving the heart and lungs. Its unique imaging capabilities make it a promising tool for assessing acute chest pain [35].

Coronary artery disease (CAD), a leading cause of acute chest pain, is often diagnosed using modalities like angiography and CT coronary angiography. Nevertheless, MRI offers several advantages, particularly in patients who may be at higher risk for radiation exposure or nephrotoxicity from contrast agents used in CT. Cardiac MRI can evaluate myocardial viability, perfusion, and cardiac function without ionizing radiation. Physiology such as stress testing can also be integrated into an MRI protocol to provide additional insight into myocardial ischemia. In this way, MRI serves as a comprehensive non-invasive tool for CAD evaluation [36].

Acute chest pain can often stem from pulmonary issues, such as pulmonary embolism or pneumonia. While CT pulmonary angiography is the gold standard for evaluating pulmonary embolism, MRI can be particularly useful in certain populations where radiation exposure poses significant risks, such as pregnant women. MRI can visualize vascular structures and assess pulmonary perfusion and ventilation. Techniques like Magnetic Resonance Angiography (MRA) and functional MRI allow for the evaluation of not just vessel abnormalities but also lung tissue integrity and function [37].

Aortic dissection represents another acute condition that warrants precision in diagnostic imaging. Detecting such a life-threatening event in a timely manner is crucial. MRI excels in this context due to its high spatial resolution and ability to produce detailed images of the aorta without radiation. MRI allows clinicians to visualize both the true and false lumens within the aorta, assess the extent of the dissection, and guide treatment decisions regarding surgical intervention. The added benefit of MRI is that it can provide functional information regarding myocardial perfusion in cases where aortic dissection may cause compromise to coronary arteries [38].

In cases where acute chest pain arises from non-cardiac and non-pulmonary sources—such as musculoskeletal pain—MRI can effectively differentiate between various thoracic structures. Conditions such as costochondritis or muscle strain can be differentiated from more serious conditions that require urgent care. MRI's superior soft tissue contrast allows for diagnostic confidence in evaluating the thoracic wall and associated musculature [39].

Despite its advantages, MRI is not without limitations. The availability of MRI in emergency settings may be hindered by inadequate staffing and resource allocation. Additionally, certain patient factors—including claustrophobia, weight limitation, and the presence of metal devices—can limit its usability [40].

Looking ahead, continued advancements in MRI technology are likely to expand its role in acute care settings. Techniques such as cardiac MRI for stress evaluation and hybrid scanners that combine MRI with CT or angiography may enhance diagnostic capabilities. Furthermore, ongoing research into the development of new contrast agents could help minimize potential risks while maximizing the diagnostic yield of MRI [41].

Comparative Effectiveness of Imaging Strategies: CT vs. MRI vs. X-ray:

Chest pain is a common symptom that presents a diagnostic challenge in clinical practice due to its potential association with a wide array of conditions, ranging from benign musculoskeletal issues to life-threatening diseases such as myocardial infarction, pulmonary embolism, or aortic dissection. The accurate assessment of chest pain often requires the use of imaging strategies to ascertain the underlying cause. The three predominant imaging modalities employed for the evaluation of chest pain are computed tomography (CT), magnetic resonance imaging (MRI), and X-ray [42].

CT scans have emerged as one of the most valuable imaging tools for evaluating chest pain, particularly in emergency settings. The primary advantage of CT, especially CT angiography, lies in its speed and ability to provide detailed cross-sectional images of thoracic structures. This enables rapid diagnosis of critical conditions such as pulmonary embolism, aortic dissection, and cardiac anomalies. With advancements in technology, CT scans are becoming increasingly available and affordable, making them a practical option for many healthcare facilities [42].

A robust application of CT in the context of chest pain is in the assessment of coronary artery disease (CAD). Coronary CT angiography (CTA) can non-invasively visualize coronary arteries, allowing for the identification of significant stenoses and potential myocardial ischemia. Multiple studies have demonstrated the high sensitivity and specificity of coronary CTA for detecting CAD, with a considerable reduction in the number of unnecessary invasive procedures, such as cardiac catheterization [43].

However, the use of CT scans is not without limitations. A significant drawback is the exposure to ionizing radiation, which raises concerns about the long-term risks associated with repeated imaging, particularly in younger patients or those with chronic conditions requiring frequent evaluations. Furthermore, CT scans may require the use of contrast agents, which can pose risks for patients with renal insufficiency or those with allergies. Despite these concerns, the rapid acquisition of images and the accuracy in detecting urgent thoracic conditions make CT a cornerstone in the imaging evaluation of chest pain [43].

Magnetic resonance imaging is another advanced imaging modality that is gaining traction in the evaluation of chest pain, although its role is less established compared to CT. MRI is particularly advantageous in assessing non-cardiac chest pain, such as conditions involving the lungs, chest wall, and mediastinum. One of the significant benefits of MRI is its non-invasive nature, as it does not involve ionizing radiation, making it a safer option for patients, particularly those requiring frequent imaging [44].

In the context of cardiac applications, cardiovascular MRI (CMR) is increasingly utilized for its ability to provide detailed images of cardiac structure and function, assess myocardial perfusion, and even evaluate cardiac tissue characteristics, such as fibrosis or inflammation. Additionally, CMR has been shown to have excellent diagnostic capabilities in differentiating between ischemic and non-ischemic heart disease [45].

Despite these advantages, the adoption of MRI for evaluating chest pain is limited by several factors. One of the primary constraints is the longer acquisition time compared to CT scans, which can be impractical in acute settings where rapid diagnosis is vital. Moreover, the presence of certain implants or devices can preclude the use of MRI due to safety concerns. The overall cost of MRI services can also be a consideration in some healthcare systems, leading to limited access for patients [46].

Chest X-ray is one of the most accessible and cost-effective imaging modalities and has traditionally served as the first-line imaging technique for patients presenting with chest pain. The primary utility of chest X-rays lies in their ability to quickly identify acute conditions such as pneumonia, pneumothorax, pleural effusion, and other significant thoracic abnormalities. For many patients with non-specific chest pain, a chest X-ray can provide immediate reassurance and may help to rule out primary causes [47].

However, the limitations of X-ray imaging are considerable when evaluating chest pain, particularly in the assessment of soft tissue structures and vascular diseases. X-rays are not particularly effective in diagnosing myocardial ischemia or acute coronary syndrome, as they mainly provide a silhouette of the thoracic structures rather than detailed imaging of the heart or great vessels. Furthermore, the relatively low sensitivity and specificity of chest X-rays in the context of acute conditions mean that further imaging, such as CT or ultrasound, may often still be required to reach a definitive diagnosis [48].

The comparative effectiveness of CT scans, MRI, and X-rays highlights the importance of a nuanced approach to imaging for chest pain. CT scans stand out for their speed and diagnostic accuracy in emergencies and have redefined the evaluation of conditions like pulmonary embolism and CAD. In contrast, MRI offers a radiation-free alternative with unique advantages for soft tissue evaluation, though its application is limited by accessibility and imaging time. X-rays, while essential for initial assessments, primarily serve to rule out significant pathology and often necessitate further imaging [49].

From a clinical perspective, the choice among these imaging modalities must consider factors including the patient's clinical condition, age, allergy history, renal function, and the need for urgency in diagnosis. Integration of clinical guidelines and multidisciplinary consultation can aid in determining the appropriate imaging strategy. As technology continues to evolve, the ongoing development of newer imaging techniques and methods for risk stratification is expected to enhance our capacity for effectively diagnosing and managing chest pain. Ultimately, the goal remains to deliver timely and accurate care, optimizing patient outcomes while minimizing unnecessary risks and healthcare costs [50].

Radiation Exposure Concerns and Risk Management in Diagnostic Imaging:

Radiation exposure in diagnostic imaging is a topic that has garnered significant attention within the medical community, regulatory bodies, and the general public. This concern arises from the dual nature of radiation as both an indispensable tool for diagnosis and a potential risk factor for health complications. Imaging modalities such as X-rays, computed tomography (CT), and nuclear medicine utilize ionizing radiation, which, at high doses, can pose health risks, including cancer. Therefore, understanding radiation exposure and implementing effective risk management strategies is critical for ensuring patient safety while maximizing the benefits of diagnostic imaging [51].

Ionizing radiation refers to radiation that carries enough energy to liberate electrons from atoms, thereby ionizing them. This type of radiation can originate from natural sources, such as cosmic rays and radon gas, or artificial sources, including medical imaging devices. In medical diagnostics, ionizing radiation plays a pivotal role by enhancing the visibility of internal structures, facilitating accurate diagnosis and timely intervention. For instance, X-rays are invaluable in diagnosing fractures, while CT scans provide detailed images of organs, tissues, and blood vessels [52].

However, exposure to ionizing radiation is not without risk. Higher doses are associated with increased odds of long-term health effects, particularly malignancies. The biological effects of radiation depend on several factors, including the type of radiation, the dose, and the sensitivity of the exposed tissues. Children are particularly susceptible to the deleterious effects of radiation due to their developing tissues and longer life expectancy, underscoring the importance of justifying and optimizing radiation use in this vulnerable population [53].

The ALARA Principle

To address radiation exposure concerns, medical professionals and regulatory authorities advocate for the ALARA principle, which stands for "As Low As Reasonably Achievable." The ALARA principle is a cornerstone of radiation safety and emphasizes minimizing exposure while maintaining the necessary quality of diagnostic images. This involves three key components: justification, optimization, and dose limitation [54].

1. **Justification**: Before any imaging procedure is performed, it is essential to ensure that the benefits outweigh the risks associated with radiation exposure. Clinicians must carefully evaluate the necessity of the scan based on the patient's clinical history and symptoms. Advances in technology and the development of alternative imaging modalities, such as ultrasound and MRI, have made it possible to reduce reliance on ionizing radiation in many cases [55].
2. **Optimization**: Once a procedure is deemed necessary, practitioners must optimize the radiation dose used during imaging. This is achieved through various methods, including using the lowest possible dose for adequate image quality, employing advanced imaging techniques that reduce exposure (e.g., dose modulation technology), and utilizing shielding techniques to protect sensitive tissues [56].
3. **Dose Limitation**: Regulatory bodies, such as the International Commission on Radiological Protection (ICRP) and the American College of Radiology (ACR), have established dose limits to protect patients and operators. These limits are based on empirical data and aim to minimize the risks associated with radiation exposure [57].

Risk Communication and Patient Education

Effective risk management in diagnostic imaging also necessitates robust communication strategies. It is imperative that healthcare providers discuss the rationale for imaging procedures with patients, including the potential risks and benefits. Informed patients are more likely to engage in shared decision-making, thereby increasing trust in healthcare providers [57].

Patient education should encompass the various imaging modalities available, the associated radiation doses, and alternative diagnostic options. Providing visual aids or risk comparison charts can enhance understanding and allow patients to make informed choices. Furthermore, patient records should include detailed information about prior imaging procedures to prevent unnecessary repeat scans, thus averting cumulative radiation exposure [58].

The implementation of effective risk management strategies in diagnostic imaging is supported by robust regulatory frameworks and guidelines.

Various organizations – including the World Health Organization (WHO), the United States Food and Drug Administration (FDA), and the National Council on Radiation Protection and Measurements (NCRP) – provide guidelines on safe imaging practices, emphasizing the importance of radiation safety training for healthcare practitioners [58].

Moreover, initiatives aimed at periodic audits and accreditation of imaging facilities help ensure compliance with best practices and regulatory requirements. Radiology departments should regularly assess their radiation dose levels and compare them against established benchmarks. By engaging in quality assurance programs, facilities can identify areas for improvement and foster a culture of safety centered on patient well-being [59].

As technology evolves, new imaging modalities that incorporate lower radiation doses are being developed. Innovations such as low-dose CT scanning, digital X-ray imaging, and advanced imaging software hold promise for reducing radiation exposure without compromising diagnostic quality. Additionally, the integration of artificial intelligence (AI) into radiology has the potential to improve image acquisition and interpretation, enabling more accurate diagnoses with reduced exposure times [59].

Furthermore, ongoing research into the biological effects of varying radiation doses may lead to refined dose recommendations tailored to individual patient risks. Understanding genetic susceptibility to radiation can allow for personalized approaches to imaging, mitigating risks for sensitive populations while still providing necessary diagnostic information [59].

Future Directions and Innovations in Radiological Assessment of Chest Pain:

Chest pain is a common clinical symptom that necessitates timely evaluation to identify potential life-threatening conditions such as acute coronary syndrome (ACS), pulmonary embolism, aortic dissection, pneumonia, or pneumothorax. Traditional methods of assessing chest pain often involve a combination of clinical evaluation, laboratory tests, and imaging studies, notably chest X-rays, computed tomography (CT) scans, and magnetic resonance imaging (MRI). As technology advances and our understanding of cardiopulmonary pathology deepens, innovative approaches to radiological assessment of chest pain are emerging, promising to enhance diagnostic accuracy, reduce patient burden, and expedite treatment initiation [60].

One of the most significant innovations poised to transform the radiological assessment of chest pain is the integration of artificial intelligence (AI) and machine learning. AI algorithms can analyze imaging studies with a speed and accuracy that surpasses traditional human interpretation. For instance, algorithms developed for various imaging modalities—including chest X-rays and CT angiography—are being trained to detect subtle changes in radiological images that may indicate underlying pathologies. Studies have shown that AI can proficiently identify acute coronary syndromes, pulmonary embolisms, and even pneumonia, often with diagnostic performance metrics comparable to, or exceeding, that of experienced radiologists [60].

As hospitals increasingly adopt AI-driven tools, these algorithms can assist clinicians by highlighting potential areas of concern, thus reducing the time to definitive diagnosis. Additionally, AI can continuously learn and improve its algorithms based on a growing database of cases, enabling enhanced detection capabilities. Beyond diagnosis, AI has the potential to predict patient outcomes based on imaging features, providing critical information that could shape treatment pathways. These developments not only hold the promise of more accurate diagnosis but may also allow for the triage of patients based on risk level, optimizing resource allocation within busy emergency departments [60].

Advanced Imaging Modalities

Future innovations in radiological assessment will also be characterized by advancements in imaging technologies. While conventional imaging studies such as X-rays and CT scans have played a pivotal role in the evaluation of chest pain, enhanced modalities are on the horizon, offering improved resolution and functional assessment [61].

1. **High-Resolution CT**: Advances in CT imaging—such as high-resolution techniques and dual-energy CT—are expanding the capabilities of this modality in chest pain assessment. These technologies provide detailed anatomical

and functional information about the heart and lungs. Dual-energy CT, which captures images at two different energy levels, can distinguish between different types of tissues, enhancing the detection of subtle embolisms or nodules that may not be apparent on standard imaging [61].

2. **Cardiac MRI**: Magnetic resonance imaging is becoming increasingly relevant in the assessment of chest pain, particularly in cases where traditional imaging may be inconclusive. Cardiac MRI offers a non-invasive solution for evaluating myocardial viability and ischemia without radiation exposure. Advancements in cardiac-specific imaging techniques, including T1 and T2 mapping, are enhancing the ability to detect subtle myocardial abnormalities related to ischemia or inflammation, thus providing critical insights that could influence management decisions [61].

3. **Positron Emission Tomography (PET)**: Incorporating PET scans in the evaluation of chest pain offers a unique advantage due to their ability to assess both morphology and metabolic activity. PET imaging allows for the evaluation of coronary blood flow and myocardial perfusion, providing crucial information in cases where traditional assessments may not yield definitive results [61].

Integrative Approaches and Biomarker Utilization

An exciting avenue for the future of radiological assessment is the integration of imaging data with clinical and laboratory findings through advanced data analytics and algorithms. By creating a multidimensional approach, clinicians can synthesize imaging results with biomarkers, electronic health records, and genomic data to provide a holistic view of the patient’s condition [62].

For instance, incorporating serum markers such as high-sensitivity troponin alongside imaging studies could refine risk stratification in patients with chest pain. Radiologists may utilize combined data to identify patterns that correlate with particular diagnoses, significantly enhancing the interpretive value of radiologic findings. Proposals for artificial intelligence systems that aggregate imaging data with other clinical parameters hold promise for developing risk prediction models, which can guide decision-making in acute care settings [63].

In the wake of recent global health challenges, particularly the COVID-19 pandemic, telemedicine has burgeoned, enabling remote consultations and evaluations. This trend extends into radiological assessments of chest pain, as remote imaging review becomes feasible. Utilizing cloud-based imaging platforms allows radiologists to access studies from any location, facilitating prompt interpretation and consultation without the constraints of physical presence [64].

Moreover, tele-radiology services can expand access to expert radiological interpretations, particularly in rural or underserved areas where healthcare resources may be limited. Remote assessments allow for timely diagnosis and management recommendations, optimizing patient flow and resource utilization in acute care settings [65].

Conclusion:

In conclusion, the radiological evaluation of acute chest pain is a pivotal component in establishing an accurate diagnosis and informing effective management strategies. This review highlights the strengths and limitations of various imaging modalities, including chest radiography, computed tomography, and magnetic resonance imaging. Each imaging technique plays a distinct role, with chest X-rays serving as initial screening tools, while CT angiography provides rapid and comprehensive assessment capabilities for critical conditions such as pulmonary embolism and coronary artery disease. MRI, though less commonly deployed in acute scenarios, offers valuable insights for specific pathologies where soft tissue characterization is essential.

As the landscape of diagnostic imaging continues to evolve, it is crucial to balance the need for rapid diagnosis with considerations of patient safety, particularly regarding radiation exposure. A tailored approach that integrates clinical judgment, patient history, and appropriate imaging strategies will enhance diagnostic accuracy and overall patient outcomes. Continued advances in imaging technology and techniques promise to further refine our ability to assess acute chest pain, ultimately leading to more efficient and effective patient care in emergency settings. Future research will be vital in exploring innovative imaging methods and optimizing workflows to ensure the best possible outcomes for patients presenting with this complex and potentially life-threatening symptom.

References:

1. Fryback DG, Thornbury JR. The efficacy of diagnostic imaging. Med Decis Making. 1991;11:88–94. - PubMed

2. Douglas PS, Patel MR, Bailey SR, et al. Hospital variability in the rate of finding obstructive coronary artery disease at elective, diagnostic coronary angiography. J Am Coll Cardiol. 2011;58:801–9. - PubMed

3. Douglas PS. Improving imaging: our professional imperative. J Am Coll Cardiol. 2006;48:2152–5. - PubMed

4. Shaw LJ, Min JK, Hachamovitch R, et al. Cardiovascular imaging research at the crossroads. J Am Coll Cardiol Img. 2010;3:316–24. - PubMed

5. Mowatt G, Cummins E, Waugh N, et al. Systematic review of the clinical effectiveness and cost-effectiveness of 64-slice or higher computed tomography angiography as an alternative to invasive coronary angiography in the investigation of coronary artery disease. Health Technol Assess. 2008;12:iii–iv, ix-143. - PubMed

6. National Institute for Health and Care Excellence [December 4, 2015]; Chest pain of recent onset: assessment and diagnosis [CG95] 2010. - PubMed

7. Ladapo JA, Blecker S, Douglas PS. Physician decision making and trends in the use of cardiac stress testing in the United States: an analysis of repeated cross-sectional data. Ann Intern Med. 2014;161:482–90. - PMC - PubMed

8. Hoffmann U, Truong QA, Schoenfeld DA, et al. ROMICAT-II Investigators. Coronary CT angiography versus standard evaluation in acute chest pain. N Engl J Med. 2012;367:299–308. - PMC - PubMed

9. Boyle RM. Value of rapid-access chest pain clinics. Heart. 2007;93:415–6. - PMC - PubMed

10. Huynh K. Imaging. Effect of CT coronary angiography on the diagnosis and outcomes of patients with CAD. Nat Rev Cardiol. 2015;12:258. - PubMed

11. Douglas PS, Hoffmann U, Patel MR, et al. PROMISE Investigators. Outcomes of anatomical versus functional testing for coronary artery disease. N Engl J Med. 2015;372:1291–300. - PMC - PubMed

12. Goldstein JA, Chinnaiyan KM, Abidov A, et al. CT-STAT Investigators. The CT-STAT (Coronary Computed Tomographic Angiography for Systematic Triage of Acute Chest Pain Patients to Treatment) trial. J Am Coll Cardiol. 2011;58:1414–22. - PubMed

13. SCOT-HEART investigators. CT coronary angiography in patients with suspected angina due to coronary heart disease (SCOT-HEART): an open-label, parallel-group, multicentre trial. Lancet. 2015;385:2383–91. - PubMed

14. Litt HI, Gatsonis C, Snyder B, et al. CT angiography for safe discharge of patients with possible acute coronary syndromes. N Engl J Med. 2012;366:1393–403. - PubMed

15. Schulman-Marcus J, Danad I, Truong QA. State-of-the-art updates on cardiac computed tomographic angiography for assessing coronary artery disease. Curr Treat Options Cardiovasc Med. 2015;17:398. - PubMed

16. Cheng VY, Berman DS, Rozanski A, et al. Performance of the traditional age, sex, and angina typicality-based approach for estimating pretest probability of angiographically significant coronary artery disease in patients undergoing coronary computed tomographic angiography: results from the multinational

coronary CT angiography evaluation for clinical outcomes: an international multicenter registry (CONFIRM). Circulation. 2011;124:2423–32, 1-8. - PMC - PubMed

17. Daly CA, Clemens F, Sendon JLL, et al. The clinical characteristics and investigations planned in patients with stable angina presenting to cardiologists in Europe: from the Euro Heart Survey of Stable Angina. Eur Heart J. 2005;26:996–1010. - PubMed

18. Fihn SD, Gardin JM, Abrams J, et al. 2012 ACCF/AHA/ACP/AATS/PCNA/SCAI/STS guideline for the diagnosis and management of patients with stable ischemic heart disease: a report of the American College of Cardiology Foundation/American Heart Association task force on practice guidelines, and the American College of Physicians, American Association for Thoracic Surgery, Preventive Cardiovascular Nurses Association, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons. J Am Coll Cardiol. 2012;60:e44–e164. - PubMed

19. Sekhri N, Feder GS, Junghans C, et al. How effective are rapid access chest pain clinics? Prognosis of incident angina and non-cardiac chest pain in 8762 consecutive patients. Heart. 2007;93:458–63. - PMC - PubMed

20. Task Force Members. Montalescot G, Sechtem U, et al. 2013 ESC guidelines on the management of stable coronary artery disease. Eur Heart J. 2013;34:2949–3003. - PubMed

21. Layritz C, Schmid J, Achenbach S, et al. Accuracy of prospectively ECG-triggered very low-dose coronary dual-source CT angiography using iterative reconstruction for the detection of coronary artery stenosis: comparison with invasive catheterization. Eur Heart J Cardiovasc Imaging. 2014;15:1238–45. - PubMed

22. Douglas PS, Zhang Y, Hachamovitch R, et al. Interobserver agreement in the interpretation of myocardial perfusion SPECT studies. J Nucl Cardiol. 2006;13:585–93. - PubMed

23. Huynh K. Role of cardiac CT in the evaluation of coronary artery disease. Nat Rev Cardiol. 2012;9:81. - PubMed

24. Schroeder S, Achenbach S, Bengel F, et al. Cardiac computed tomography: indications, applications, limitations, and training requirements. Eur Heart J. 2008;29:531–56. - PubMed

25. Dedic A, Genders TS, Nieman K, Hunink MGM. Imaging strategies for acute chest pain in the emergency department. AJR Am J Roentgenol 2013; 200: W26–38. doi: 10.2214/AJR.11.8296

26. Hulten E, Pickett C, Bittencourt MS, Villines TC, Petrillo S, Di Carli MF, et al. Outcomes after coronary computed tomography angiography in the emergency department: a systematic review and meta-analysis of randomized, controlled trials. J Am Coll Cardiol 2013; 61: 880–92. doi: 10.1016/j.jacc.2012.11.061

27. Lantanzi F, Picano E, Adamo E, Varga A. Dobutamine stress echocardiography. Drug Safety 2000; 22: 251–62. doi: 10.2165/00002018-200022040-00001

28. Moy E, Barrett M, Coffey R, Hines AL, Newman-Toker DE. Missed diagnoses of acute myocardial infarction in the emergency department: variation by patient and facility characteristics. Diagnosis (Berl) 2015; 2: 29–40. doi: 10.1515/dx-2014-0053

29. Sharedalal P, Gerard P, Jain D. Pharmacological stress myocardial perfusion imaging after an inadequate exercise stress test. J Nucl Cardiol 2022; 29: 1796–98. doi: 10.1007/s12350-021-02661-3

30. Broncano J, Bhalla S, Caro P, Hidalgo A, Vargas D, Williamson E, et al. Cardiac MRI in patients with acute chest pain. Radiographics 2021; 41: 8–31. doi: 10.1148/rg.2021200084

31. Fox K, Achenbach S, Bax J, Cosyns B, Delgado V, Dweck MR, et al. Multimodality imaging in cardiology: a statement on behalf of the task force on multimodality imaging of the European association of cardiovascular imaging. Eur Heart J 2019; 40: 553–58. doi: 10.1093/eurheartj/ehy669

32. Agewall S, Beltrame JF, Reynolds HR, Niessner A, Rosano G, Caforio ALP, et al. ESC Working group position paper on myocardial infarction with non-obstructive coronary arteries. Eur Heart J 2017; 38: 143–53. doi: 10.1093/eurheartj/ehw149

33. Collet, J-P, et al. ESC guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation. Eur Heart J 2020; 42: 1289–1367. doi: 10.1093/eurheartj/ehaa909

34. Kalagara H, Coker B, Gerstein NS, Kukreja P, Deriy L, Pierce A, et al. Point-Of-Care ultrasound (POCUS) for the cardiothoracic anesthesiologist. Journal of Cardiothoracic and Vascular Anesthesia 2022; 36: 1132–47. doi: 10.1053/j.jvca.2021.01.018

35. Lim SH, Anantharaman V, Sundram F, Chan ES-Y, Ang ES, Yo SL, et al. Stress myocardial perfusion imaging for the evaluation and triage of chest pain in the emergency department: a randomized controlled trial. J Nucl Cardiol 2013; 20: 1002–12. doi: 10.1007/s12350-013-9736-9

36. Sicari R, Nihoyannopoulos P, Evangelista A, Kasprzak J, Lancellotti P, Poldermans D, et al. Stress echocardiography expert consensus statement -- executive summary: European association of echocardiography (EAE) (a registered branch of the ESC). Eur Heart J 2009; 30: 278–89. doi: 10.1093/eurheartj/ehn492

37. Brown, D. An Epidemiologic Study of Closed Emergency Department Malpractice Claims in a National Database of Physician Malpractice Insurers. Acad Emerg Med 2010; Wiley Online Library.

38. Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, Xiang J, Wang Y, Song B, Gu X, Guan L, Wei Y, Li H, Wu X, Xu J, Tu S, Zhang Y, Chen H, Cao B. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet. 2020;395:1054–1062. doi: 10.1016/S0140-6736(20)30566-3.

39. Lee TH, Goldman L. Evaluation of the patient with acute chest pain. N Engl J Med. 2000;342:1187–1195. doi: 10.1056/NEJM200004203421607.

40. Gupta N, Zhao YY, Evans CE. The stimulation of thrombosis by hypoxia. Thromb Res. 2019;181:77–83. doi: 10.1016/j.thromres.2019.07.013.

41. Takx RAP, Wichmann JL, Otani K, De Cecco CN, Tesche C, Baumann S, Mastrodicasa D, Litwin SE, Bayer RR 2nd, Nance JW, Suranyi P, Jacobs BE, Duguay TM, Vogl TJ, Carr CM, Schoepf UJ. In-Hospital Cost Comparison of Triple-Rule-Out Computed Tomography Angiography Versus Standard of Care in Patients With Acute Chest Pain. J Thorac Imaging. 2020;35:198–203. doi: 10.1097/RTI.0000000000000474.

42. Eltabbakh AR, Dawoud MA, Langer M, Moharm MA, Hamdy EA, Hamisa MF. ‘Triple-rule-out’ CT angiography for clinical decision making and early triage of acute chest pain patients: use of 320-multislice CT angiography. Egypt J Radiol Nuc M. 2019;50:1–10.

43. Chae MK, Kim EK, Jung KY, Shin TG, Sim MS, Jo IJ, Song KJ, Chang SA, Song YB, Hahn JY, Choi SH, Gwon HC, Lee

SH, Kim SM, Eo H, Choe YH, Choi JH. Triple rule-out computed tomography for risk stratification of patients with acute chest pain. J Cardiovasc Comput Tomogr. 2016;10:291–300. doi: 10.1016/j.jcct.2016.06.002.

44. Eljilany I, Elzouki AN. D-Dimer, Fibrinogen, and IL-6 in COVID-19 Patients with Suspected Venous Thromboembolism: A Narrative Review. Vasc Health Risk Manag. 2020;16:455–462. doi: 10.2147/VHRM.S280962.

45. Backus BE, Six AJ, Kelder JH, Gibler WB, Moll FL, Doevendans PA. Risk scores for patients with chest pain: evaluation in the emergency department. Curr Cardiol Rev. 2011;7:2–8. doi: 10.2174/157340311795677662.

46. Yoon YE, Wann S. Evaluation of acute chest pain in the emergency department: "triple rule-out" computed tomography angiography. Cardiol Rev. 2011;19:115–121. doi: 10.1097/CRD.0b013e31820f1501.

47. Pope JH, Aufderheide TP, Ruthazer R, Woolard RH, Feldman JA, Beshansky JR, Griffith JL, Selker HP. Missed diagnoses of acute cardiac ischemia in the emergency department. N Engl J Med. 2000;342:1163–1170. doi: 10.1056/NEJM200004203421603.

48. Tang N, Li D, Wang X, Sun Z. Abnormal coagulation parameters are associated with poor prognosis in patients with novel coronavirus pneumonia. J Thromb Haemost. 2020;18:844–847. doi: 10.1111/jth.14768.

49. Sakr Y, Giovini M, Leone M, Pizzilli G, Kortgen A, Bauer M, Tonetti T, Duclos G, Zieleskiewicz L, Buschbeck S, Ranieri VM, Antonucci E. Pulmonary embolism in patients with coronavirus disease-2019 (COVID-19) pneumonia: a narrative review. Ann Intensive Care. 2020;10:124. doi: 10.1186/s13613-020-00741-0.

50. Dan S, Pant M, Upadhyay SK. The Case Fatality Rate in COVID-19 Patients With Cardiovascular Disease: Global Health Challenge and Paradigm in the Current Pandemic. Curr Pharmacol Rep. 2020:1–10. doi: 10.1007/s40495-020-00239-0.

51. Lee HY, Yoo SM, White CS. Coronary CT angiography in emergency department patients with acute chest pain: triple rule-out protocol vs dedicated coronary CT angiography. Int J Cardiovasc Imaging. 2009;25:319–326. doi: 10.1007/s10554-008-9375-4.

52. Kelly A-M, Keijzers G, Klim S, Craig S, Kuan WS, Holdgate A, et al. Epidemiology and outcome of older patients presenting with dyspnoea to emergency departments. Age Ageing 2021; 50: 252–57. doi: 10.1093/ageing/afaa121.

53. Haga T, Fukuoka M, Morita M, Cho K, Tatsumi K. Computed tomography for the diagnosis and evaluation of the severity of community-acquired pneumonia in the elderly. Intern Med 2016; 55: 437–41. doi: 10.2169/internalmedicine.55.5556.

54. Long B, Long D, Koyfman A. Emergency medicine evaluation of community-acquired pneumonia: history, examination, imaging and laboratory assessment, and risk scores. J Emerg Med 2017; 53: 642–52. doi: 10.1016/j.jemermed.2017.05.035.

55. Ray P, Birolleau S, Lefort Y, Becquemin M-H, Beigelman C, Isnard R, et al. Acute respiratory failure in the elderly: etiology, emergency diagnosis and prognosis. Crit Care 2006; 10: R82. doi: 10.1186/cc4926.

56. Vogel-Claussen J, Elshafee ASM, Kirsch J, et al. ACR appropriateness criteria. J Am Coll Radiol 2017; 14: S127–37. doi: 10.1016/j.jacr.2017.01.032.

57. Basi SK, Marrie TJ, Huang JQ, Majumdar SR. Patients admitted to hospital with suspected pneumonia and normal chest radiographs: epidemiology, microbiology,

and outcomes. Am J Med 2004; 117: 305–11. doi: 10.1016/j.amjmed.2004.03.029.

58. Self WH, Courtney DM, McNaughton CD, Wunderink RG, Kline JA. High discordance of chest x-ray and computed tomography for detection of pulmonary opacities in ED patients: implications for diagnosing pneumonia. Am J Emerg Med 2013; 31: 401–5. doi: 10.1016/j.ajem.2012.08.041.

59. Mandell LA, Wunderink RG, Anzueto A, Bartlett JG, Campbell GD, Dean NC, et al. Infectious diseases society of america/american thoracic society consensus guidelines on the management of community-acquired pneumonia in adults. Clin Infect Dis 2007; 44 Suppl 2: S27–72. doi: 10.1086/511159.

60. McDonagh TA, Metra M, Adamo M, Gardner RS, Baumbach A, Böhm M, et al. 2021 ESC guidelines for the diagnosis and treatment of acute and chronic heart failure. Eur Heart J 2021; 42: 3599–3726. doi: 10.1093/eurheartj/ehab368.

61. Jokert C, Chung JH, Ackman JB, et al. ACR appropriateness criteria. J Am Coll Radiol 2018; 15: S240–51. doi: 10.1016/j.jacr.2018.09.012.

62. Kitazono MT, Lau CT, Parada AN, Renjen P, Miller WT. Differentiation of pleural effusions from parenchymal opacities: accuracy of bedside chest radiography. AJR Am J Roentgenol 2010; 194: 407–12. doi: 10.2214/AJR.09.2950.

63. Fonseca C, Mota T, Morais H, Matias F, Costa C, Oliveira AG, et al. The value of the electrocardiogram and chest X-ray for confirming or refuting a suspected diagnosis of heart failure in the community. Eur J Heart Fail 2004; 6: 807–12. doi: 10.1016/j.ejheart.2004.09.004.

64. Laribi S, Keijzers G, van Meer O, Klim S, Motiejunaite J, Kuan WS, et al. Epidemiology of patients presenting with dyspnea to emergency departments in Europe and the Asia-Pacific region. Eur J Emerg Med 2019; 26: 345–49. doi: 10.1097/MEJ.0000000000000571.

65. Parshall MB, Schwartzstein RM, Adams L, Banzett RB, Manning HL, Bourbeau J, et al. An official American thoracic Society statement: update on the mechanisms, assessment, and management of dyspnea. Am J Respir Crit Care Med 2012; 185: 435–52. doi: 10.1164/rccm.201111-2042ST.