ONTARIO HEALTH TECHNOLOGY ASSESSMENT SERIES

Single-Exposure, Dual-Energy Subtraction Flat Panel X-Ray Detectors

A Health Technology Assessment

November 2024

Ontario Health

Key Messages

What Is This Health Technology Assessment About?

Conventional radiography (x-ray) is used to generate images of tissues and structures inside the body and can be used to detect pneumonia, pulmonary nodules, and pneumothorax (all of these conditions affect the lungs), as well as to see lines and tubes that may have been placed there during medical procedures. In some clinical situations, the overlap of body structures can obscure certain radiographic findings, making it difficult to detect abnormalities in the x-ray. Single-exposure, dual-energy subtraction (DES) flat panel x-ray detectors produce a conventional x-ray image plus a DES soft tissue x-ray image (an image that removes the bone) and a DES bone x-ray image (an image that removes the soft tissue) to minimize the limitations presented by anatomical overlap.

This health technology assessment looked at the accuracy of single-exposure, DES flat panel x-ray detectors for conditions such as pneumonia, pneumothorax, pulmonary nodules, and for seeing any lines and tubes inside the body. It also evaluated the impact of the use of the device on patient management and clinical outcomes, and on the radiologist's confidence in the diagnosis. Additionally, this assessment looked at the budget impact of publicly funding single-exposure, DES x-ray detectors and the experiences, preferences, and values of health care providers.

What Did This Health Technology Assessment Find?

The use of single-exposure, DES flat panel x-ray detectors may lead to an improvement in the ability to see calcium deposits that may be present in lung nodules (abnormal growths in the lungs), compared with conventional x-ray. The evidence is less clear that single-exposure, DES flat panel x-ray detectors are better than conventional x-rays for visualizing lines and tubes that have been placed in the patient during procedures. It is also unclear if they improve the radiologist's confidence in their diagnoses or whether they affect the amount of time required to review the x-ray images, compared with conventional x-ray. We did not find evidence for the use of the technology for most populations and outcomes that we intended to evaluate, including the impact on patient management and clinical outcomes. We estimate that purchasing 3 detectors to retrofit existing x-ray machines may cost $12,137.

Participants who had direct experience retrofitting x-ray systems to be compatible with the DES flat panel x-ray detector reported it was not a seamless process. Participants who operated the retrofitted x-ray systems reported on issues that negatively impacted workflow. People who viewed and interpreted the images produced by DES detectors spoke positively about their experience with the technology and expressed an increase in confidence when making a diagnosis.

Acknowledgements

This report was developed by a multidisciplinary team from Ontario Health. The primary clinical epidemiologist was Vania Costa, the secondary clinical epidemiologist was Shayan Sehatzadeh, the primary medical librarian was Caroline Higgins, the secondary medical librarian was Corinne Holubowich, the primary health economist was Yuan Zhang, the secondary health economist was Olga Gajic-Veljanoski, and the primary patient engagement analyst was Jigna Mistry.

The medical editor was Tim Maguire. Others involved in the development and production of this report were Justin Sutherland, Claude Soulodre, Caroline Higgins, Susan Harrison, Sarah McDowell, Chunmei Li, Jigna Mistry, Andrée Mitchell, Charles de Mestral, and Nancy Sikich.

We would like to thank the following people and organizations for lending their expertise to the development of this report:

- Kali Barrett, University Health Network
- Marco Buccella, Sunnybrook Health Sciences Centre
- Nancy Dabir, Hamilton Health Sciences
- Carole Dennie, Ontario Health
- Julian Dobranowski, Ontario Health
- Carla Girolametto, Grand River General Hospital
- Paul Hosek, Grand River General Hospital
- David A. Koff, McMaster University
- Deanna Langer, Ontario Health
- Nazly Mansouri, Sunnybrook Health Sciences Centre
- Donna E. Maziak, The Ottawa Hospital
- Anastasia Oikonomou, Sunnybrook Health Sciences Centre
- Narinder S. Paul, Western University
- Patrik Rogalla, University Health Network
- Kednapa Thavorn, Ottawa Hospital Research Institute
- Vikram Venkatesh, Grand River General Hospital
- William Wong, School of Pharmacy, University of Waterloo
- KA Imaging Inc.

The statements, conclusions, and views expressed in this report do not necessarily represent the views of those we consulted.

Citation

Ontario Health. Single-exposure, dual-energy subtraction flat panel x-ray detectors: a health technology assessment. Ont Health Technol Assess Ser [Internet]. 2024 Nov;24(9):1–76. Available from: hqontario.ca/evidence-to-improve-care/health-technology-assessment/reviews-and-recommendations/single-exposure-dual-energy-subtraction-flat-panel-x-ray-detectors

Abstract

Background

In medicine, x-rays are used to generate images of tissues and structures inside the body. X-rays are emitted by a source device and, after passing through the body, strike a detector, which forms an image of the tissues and structures the x-rays passed through. Dual-energy subtraction (DES) x-ray systems use radiation of different energy spectra (energy levels) and the principle of differential absorption characteristics of bone and soft tissue to produce separate bone and soft tissue x-ray images, in addition to a conventional x-ray image. The aim is to minimize potential issues with anatomical overlap with conventional x-ray that may obscure some findings. Single-exposure, DES flat panel x-ray detectors produce a conventional x-ray image in addition to DES bone and soft tissue x-ray images using a single x-ray exposure. We conducted a health technology assessment of single-exposure, DES digital flat panel x-ray detectors in adults for indications such as pneumonia, pneumothorax, and pulmonary nodules, and for visualizing lines and tubes, compared with conventional x-ray. Our assessment included an evaluation of the diagnostic accuracy, the impact on diagnostic confidence, patient management and clinical outcomes, the budget impact of publicly funding the technology, and the experiences, preferences, and values of health care providers.

Methods

We performed a systematic literature search of the clinical evidence. We assessed the risk of bias of each included study using the QUADAS-C tool and the quality of the body of evidence according to the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) Working Group criteria. We performed a systematic literature search on the economic evidence of single-exposure, DES flat panel x-ray detectors. We did not conduct a primary economic evaluation because of limited evidence on the implications of this technology. We analyzed the budget impact of publicly funding single-exposure, DES flat panel detectors in Ontario hospitals. To contextualize the potential value of single-exposure, DES flat panel x-ray detectors, we spoke with people with expertise in diagnostic imaging, including radiologists and other health care practitioners.

Results

The clinical evidence review identified 2 eligible observational studies that assessed the use of single-exposure, DES flat panel x-ray detectors to generate DES bone and soft tissue x-ray images and a conventional x-ray image. The findings of 1 study suggest an improvement in the sensitivity and specificity for the detection of pulmonary nodule calcification with the use of single-exposure, DES soft tissue and conventional x-ray images compared with using a conventional x-ray image alone (results were statistically significant for 2 out of 5 reviewers; GRADE: Low). In one study, x-ray image reviewers reported an improvement in the visibility of the tips of lines and tubes (although these were visualized with the conventional x-ray image alone) in all patients and an improvement in the diagnostic confidence in 16 (57.1%) patients, with no difference in the time to review the images with the use of single-exposure, DES bone and soft tissue x-ray images plus the conventional x-ray image compared with using the conventional x-ray image alone, but the evidence is very uncertain (GRADE: Very low).

The economic evidence review identified 1 costing study in the US setting. This analysis suggested adoption of single-exposure, DES x-ray detectors may lead to cost savings. However, this study was deemed not directly applicable to the Ontario setting. The cost-effectiveness of single-exposure, DES flat panel x-ray detectors is therefore unknown. Owing to the limited evidence on the impact of these detectors on short-term outcomes such as diagnostic accuracy and workflow, and long-term costs and health outcomes, we did not conduct a primary economic evaluation. Our budget impact analysis estimated that, for a typical community hospital, purchasing 3 detectors to retrofit existing x-ray machines would lead to an additional cost of $12,137 per institution. However, there is a large degree of uncertainty around the downstream costs and benefits of this technology.

We interviewed 20 health care providers who had expertise with x-ray systems. Those who had the opportunity to interpret the x-ray images produced by a single-exposure, DES detector in a clinical setting were supportive of this technology and perceived an increase in confidence with diagnosing patients. Retrofitting existing x-ray systems to be compatible with the single-exposure, DES detector posed a challenge for operators as it was not a seamless process. Those who operated the retrofitted x-ray systems using the single-exposure, DES detector commented on issues related to workflow, including the physical specifications, connectivity, battery life, and maneuverability as barriers to use. Participants who did not have experience using the DES detector technology expressed uncertainty regarding the benefits compared to the alternative options currently in use in Ontario, such as image enhancing software, emerging artificial intelligence technology, and low-dose CT scanning. None of the users had experience with a fully integrated mobile x-ray system (i.e., a mobile x-ray system that did not require retrofitting to be compatible with the single-exposure, DES detector).

Conclusions

The use of single-exposure, DES flat panel x-ray detectors may lead to an improvement in the sensitivity and specificity to detect pulmonary nodule calcification compared with conventional x-ray, but the evidence is very uncertain for its effect on the visibility of the tips of lines and tubes, diagnostic confidence, and time to review the x-ray images compared with conventional x-ray. Evidence gaps include lack of evidence for the use of the technology for most populations and outcomes that we sought to evaluate. Due to limited clinical and economic evidence, the cost-effectiveness of single-exposure, DES flat panel x-ray detectors is currently unknown. We estimate that purchasing 3 detectors to retrofit with existing x-ray machines may lead to an additional cost of $12,137 per institution. Users of single-exposure, DES x-ray detectors who viewed and interpreted the images produced spoke positively about their experience with the technology and expressed an increase in confidence when making a diagnosis. Participants who operated the retrofitted single-exposure, DES x-ray detector commented on issues that negatively impacted their workflow. The experiences of providers with a fully integrated system are unknown at this time.

Table of Contents

List of Tables

List of Figures

Objective

This health technology assessment (HTA) evaluates the diagnostic accuracy of single-exposure, dual-energy subtraction (DES) digital flat panel x-ray detectors in adults for indications such as pneumonia, pneumothorax, pulmonary nodules, visualizing lines, and tubes compared with conventional x-ray. It also evaluates the impact of the use of the device on patient management and clinical outcomes, and on the radiologist's confidence in the diagnosis compared with conventional x-ray. Additionally, the HTA evaluates the budget impact of publicly funding single-exposure, DES digital flat panel x-ray detectors and the experiences, preferences, and values of healthcare providers.

Background

Current Imaging Options

Conventional X-Ray Systems

X-rays are a type of high-energy electromagnetic radiation that can pass through objects, including the body.[1] In medicine, x-rays are used to generate images of tissues and structures inside the body and can be used to detect bone fractures, tumors, pneumonia, calcifications, foreign objects, etc.[1] To obtain an x-ray image (a radiograph), a patient is positioned between an x-ray source and a detector.[1] After the x-rays are emitted at the source, they pass through the body and strike a detector on the other side of the patient. The detector produces an image of the tissue the x-rays pass through.[1]

X-rays are attenuated (absorbed) to different extents depending on the material composition of the different structures and tissues that they pass through before reaching the detector.[1] Bones absorb x-rays to a higher extent; therefore, bony structures appear whiter than other tissues on a radiograph, while less radiologically dense tissues (e.g., muscle, lungs) appear as shades of grey.[1]

Types of x-ray detectors include radiographic film, computed radiography, and digital flat panel detectors.[1-3] X-ray systems can be fixed in a dedicated room or can be mobile (able to be moved to different rooms).[4] Mobile x-ray systems allow radiography to be done in circumstances where it's not feasible for the patient to be moved to a different room or a different facility[4] (e.g., patients hospitalized in the intensive care unit [ICU]).[4,5] Although a mobile x-ray's image quality is considered limited, mobile radiography is considered a valuable diagnostic tool.[5]

Chest radiography is the most common imaging test for the detection of chest conditions due to its low dose, low cost,[3,6] and accessibility.[7,8] It can help detect some thoracic diseases as well as inform clinical decisions in managing these conditions.[7] However, in some clinical situations, the overlap of anatomic structures can obscure certain radiographic findings (e.g., pulmonary nodules), affecting diagnostic accuracy.[3,8]

A radiologist usually analyzes the x-ray images and sends a report with the interpretation of the findings to the requesting physician.[9] In certain contexts (e.g., the ICU), chest radiographs may be initially interpreted by the treating physician to make treatment decisions before being assessed by the radiologist.[10,11]

X-rays produce ionizing radiation, which can harm body tissue.[1] The risk of developing cancer from this exposure is considered generally small, but the effects are cumulative, with the risk increasing with the number of x-ray exposures over a person's lifetime.[1] As children are more sensitive to ionizing radiation and have a longer life expectancy, the risk of developing cancer from x-ray radiation is higher than in adults.[1]

Dual-Energy Subtraction X-Ray Systems

Dual-energy subtraction x-ray systems use radiation in different energy spectra (energy levels) and the principle of differential absorption characteristics of different body structures (e.g., bone and soft tissue) to produce separate bone and soft tissue x-ray images in addition to a conventional x-ray image.[12,13] The goal is to minimize the issues caused by anatomical overlap that may be experienced with conventional x-rays,[3] potentially improving the visualization of vascular access lines, indwelling tubes, and devices (e.g., coronary stents), and improving the visualization of tissues "hidden" behind these devices.[12]

Principles of DES X-Ray Systems

The principles of dual-energy technology were developed in the 1980s,[14] and the technology became available in clinical practice within the last 20 years.[12] The absorption of x-rays by the materials the x-rays pass through is proportional to their atomic number.[12] For instance, soft tissues, which are composed of elements with low atomic numbers absorb fewer x-rays than tissues such as bones and calcified tissues (and implanted medical devices), which are composed of elements with higher atomic numbers.[12]

X-ray absorption is also inversely proportional to the x-ray's energy level. For example, low-energy x-rays have a higher absorption level than do high-energy x-rays, but the absorption differential is more pronounced in bone than in soft tissue due to the higher atomic number of its constituent parts .[12,15] This higher attenuation (absorption) differential of x-rays by bone compared with soft tissue at different x-ray energy levels (high and low energy) permits image processing to create images that either emphasize or subtract soft tissue and bone structures.[12,15] Dual-energy subtraction x-ray systems thus produce 3 x-ray images: conventional, DES bone (subtracting the soft tissue), and DES soft tissue (subtracting the bone) x-ray images.[15]

There are 2 main types of DES x-ray systems: dual and single exposure.[12] Dual-exposure systems are described here, single-exposure systems are described below, in "Health Technology Under Review."

Dual-Exposure DES X-Ray Systems

In dual-exposure DES systems, 2 consecutive exposures at different energy levels are generated by an x-ray source approximately 0.2 seconds apart[13,16] and a flat panel detector with a fast readout capability is used to detect the x-rays.[10,15] The first x-ray exposure is generated with a high-energy beam (~120 kilovolts peak [kVp]), followed by a fast image readout by the flat panel detector.[12,15] Subsequently, a low-energy beam (~60 kVp) x-ray exposure is generated, followed by another fast image readout.[12,15] The resulting images undergo energy subtraction using algorithms and image processing to produce the conventional, DES soft tissue, and DES bone x-ray images.[12-14,16]

Health Technology Under Review

Single-Exposure, DES Flat Panel X-Ray Detectors

Single-exposure, DES flat panel x-ray detectors are usually composed of 2 imaging layers of different thicknesses—a top, thinner layer that detects high- and low-energy x-rays, but preferentially absorbs low-energy x-rays, and a bottom, thicker layer that absorbs high-energy x-rays.[8,17] Additionally, the detector usually includes a copper middle layer that filters out residual low-energy x-rays not absorbed by the top layer.[8,17] When a single x-ray beam (exposure) is generated by an x-ray system, the full x-ray spectrum (high and low energy) is detected by the top layer to produce a conventional radiograph (conventional x-ray image).[8,13-15] The DES bone and soft tissue x-ray images are produced by weighted subtraction of the images from the top and bottom layers using a post-processing algorithm.[8,13,14]

Devices

The Reveal 35C flat panel detector is a 3-layer, digital DES flat panel x-ray detector that produces a conventional x-ray image, along with DES bone and soft tissue images using a single x-ray exposure (SpectralDR technology).[18,19] The conventional digital x-ray image is produced by linearly summing the signal from all 3 layers.[19] The DES bone and soft tissue x-ray images are produced by a logarithmic subtraction algorithm using the signal received by all 3 layers.[19]

The Calneo Dual is a 2-layer digital flat panel x-ray detector that includes DES processing using a single x-ray exposure.[20] The detector produces 3 images (conventional, DES bone, and DES soft tissue x-ray images).[20]

Differences Between Dual- and Single-Exposure, DES X-Ray Systems

With dual-exposure DES x-ray systems, the large energy differential between the 2 x-ray exposures leads to a higher signal-to-noise ratio and a better separation of bone and soft tissue compared to single-exposure DES,[12] leading to a greater tissue contrast.[2,12] The radiation dose is higher than with conventional radiography due to the 2 separate exposures.[13] Since the 2 exposures are not simultaneous, patient movement between exposures may create motion artefacts in the images, affecting their quality.[19] Dual-exposure systems, which are not widely available, require a dedicated room.[13,15]

Single-exposure, DES flat panel x-ray detectors generate images with 1 x-ray exposure, which avoids patient movement artefacts. However, the middle copper layer absorbs part of the x-rays, affecting the radiation dose efficiency of the detector.[17,19] Also, since only 1 x-ray exposure is used, the energy separation relies completely on the flat panel detector,[15] which may result in a limited energy differential between the 2 images and therefore a limited separation of different tissues (i.e., single-exposure DES has a relatively low signal-to-noise ratio).[12,15]

Other Technologies That Enhance the Quality of X-Ray Images

Different technologies that remove bones and calcified structures from chest radiographs have been developed,[21] including software that aims to enhance the quality of the x-ray image; e.g., improving the visualization of lines, tubes, and pneumothoraces.[11] Grey-scale inversion is a tool that allows viewing of the inverted x-ray image (i.e., showing bones in dark grey rather than the usual white, and soft tissue in white instead of grey), which is expected to improve contrast perception.[22,23] Grey-scale inversion is a built-in feature on most Picture Archiving and Communication System (PACS) display workstations.[23]

Deep learning and artificial intelligence (AI) applications for medical imaging are also being developed to create chest x-ray algorithms to help clinicians detect important radiographic findings.[7] An example is software that suppresses bone in conventional chest x-ray images using advanced image processing accompanied by a recognition pattern and machine learning algorithm.[24] This type of software can be used with images obtained through conventional digital chest x-rays without requiring a specialized dual-energy x-ray system.[24] A 2018 health technology assessment (HTA) on the diagnosis of pulmonary nodules found that it was too early to make conclusions about the use of AI technology to detect pulmonary nodules.[24]

Our review focuses on single-exposure, DES digital flat panel x-ray detectors. Other non-DES bone or soft tissue suppression technologies were considered out of scope.

Intended Uses

Pulmonary Nodules

Lung cancer is the second most common cancer in Ontario; it is estimated that 1 in 13 persons in Ontario will develop lung cancer in their lifetime.[25] It is a leading cause of cancer death in part because it is not usually diagnosed before it reaches an advanced stage.[26]

An estimated 10%–70% of people with solitary pulmonary nodules will develop lung cancer; these nodules may be detected as incidental findings on chest x-rays.[27]

Chest x-rays have a relatively high rate of false-negatives (19%–72%) compared to low-dose CT scanning and are considered an inferior method to detect pulmonary nodules.[6] Factors that affect chest x-rays' ability to identify pulmonary nodules include small size, density, and the presence of overlapping structures (ribs, clavicles, mediastinum, and pulmonary vessels).[3,6,13]

According to the 2012 referral guidelines from the Canadian Association of Radiology,[28] chest x-rays may be the first imaging modality used to detect solitary pulmonary nodules, but with very limited use in nodule characterization and final diagnosis. CT scanning may demonstrate definite findings of nodule benignity, including central calcification.[28]

In Ontario, low-dose CT scanning is recommended for the screening of people at high risk of getting lung cancer.[26] In people with signs or symptoms of lung cancer, chest x-rays are recommended as a preliminary investigation.[29] People with an abnormal chest x-ray should have a chest CT scan within 2 weeks. Due to the possibility of a false negative result, patients with a negative chest x-ray result where there is a high suspicion of lung cancer should also be referred for a CT scan.[29]

The dual energy subtraction soft tissue x-ray image may improve the detection of small pulmonary nodules compared with conventional x-ray alone, particularly for nodules overlapping with bones.[6] Calcification within a pulmonary nodule suggests that it is a benign lesion.[3,21,27] Patterns of calcification are visualized on a CT scan, which is considered the reference standard for identifying calcification.[27] The accuracy of chest radiography to detect nodule calcification is estimated to be low (~50%).[21]

Pneumothorax

Pneumothorax, defined as air in the pleural space, occurs when air leaks into the space between the lung and the chest wall—the pressure from the air building up outside of the lung causes it to collapse.[30] A pneumothorax may be caused by chest injury (e.g., blunt or penetrating chest wound) or damage from underlying lung disease (e.g., chronic obstructive pulmonary disease or pneumonia) or a medical procedure (e.g., mechanical ventilation, or any procedure in which a needle is inserted into the chest).[30] A pneumothorax can be life-threatening.[30] Pneumothoraces may be diagnosed using conventional chest radiography in some cases.[10]

Mobile chest radiography, which is often used in hospital ICUs, poses technical difficulties due to difficulties with patient positioning, limited patient cooperation, and difficulties in visualizing anatomical features due to overlapping anatomical structures, chest tubes, cardiac monitoring equipment, and vascular lines.[11] The dual energy subtraction soft tissue x-ray image, by subtracting potentially overlapping bone structures from the chest x-ray, may potentially improve the diagnosis of pneumothorax.[10]

Intensive Care Unit

Chest radiography is frequently requested for people hospitalized in the ICU given the concerns about the severity of cardiopulmonary illness and the use of complex medical interventions,[31] as well as for monitoring and diagnosing different conditions.[5] Chest radiography can be used to determine the presence of conditions such as pleural effusions, pneumothoraces, and pneumonia, to visualize the positioning of lines and tubes (e.g., endotracheal tubes, central venous catheters, or PICC [peripherally inserted central catheter] lines), and to detect complications associated with malpositioning of these indwelling devices.[5,31] Malposition of central venous catheters, for instance, is estimated to occur in approximately 10% of cases[5] and can lead to complications such as pneumothorax and mediastinal hematoma; malposition of endotracheal tubes is estimated to occur in up to 15% of cases.[5]

Despite the technical difficulties noted above, mobile x-ray systems are used in hospital ICUs as patients are often unstable and may be difficult to move outside of the ICU.[5,11]

Regulatory Information

The Reveal 35C flat panel detector is approved by Health Canada as a class 2 medical device (licence number 105205[32]). The Reveal Mobi Pro mobile x-ray system that integrates the Reveal 35C flat panel detector[33] is approved by Health Canada as a class 2 medical device (licence number 111209).[34] At the time of writing this report, the Calneo Dual flat panel detector hasn't been approved by Health Canada.

Ontario, Canadian, and International Context

Conventional chest radiography is widely available in Ontario hospitals for the indications under assessment in this review. Dual-exposure DES x-ray systems are not widely used in Ontario for chest imaging.

Some Ontario hospitals temporarily used the Reveal 35C flat panel detector for indications such as detection of pulmonary nodules, pneumonia, pneumothorax, and visualizing lines and tubes, in addition to use in patients in the ICU and in outpatients; the Reveal 35C detector was integrated into fixed and mobile x-ray systems (Karim S. Karim, PhD, email communications, September 2023 to February 2024).

We are not aware that Reveal 35C is being used in other Canadian provinces.

According to the manufacturer, the Reveal 35C flat panel detector is available in some Asian countries (Karim S. Karim, PhD, video communication, September 18, 2023).

Equity Context

We use the PROGRESS-Plus framework[35] to help explicitly consider health equity in our health technology assessments. PROGRESS-Plus is a health equity framework used to identify population and individual characteristics across which health inequities may exist. These characteristics include place of residence; race or ethnicity; culture or language; gender or sex; disability; occupation; religion; education; socioeconomic status; social capital; and other key characteristics that stratify health opportunities and outcomes.

Terminology

Chest radiography describes chest x-ray examinations. Chest radiograph describes the chest x-ray image.

Expert Consultation

We engaged with experts in the specialty areas of radiology (radiologists and radiology technologists), intensive care medicine, and oncology to help inform our understanding of aspects of the health technology and our methodologies and to contextualize the evidence.

PROSPERO Registration

This health technology assessment has been registered in PROSPERO, the international prospective register of systematic reviews (CRD42024519661), available at crd.york.ac.uk/PROSPERO.

Clinical Evidence

Research Questions

Compared with conventional digital or computed radiography systems:

- What is the diagnostic accuracy of single-exposure, dual-energy subtraction flat panel x-ray detectors used for chest radiography in adults to detect conditions such as pneumonia, cavitation, pleural effusion, pneumothorax, or pulmonary nodules, and to visualize lines, tubes, catheters, or implanted medical devices?
- Does the use of single-exposure, dual-energy subtraction flat panel x-ray detectors for chest radiography in adults for the conditions listed above impact the radiologist's and treating physician's confidence in the diagnosis or treatment decision, patient management, patient outcomes, resource use, or radiation dose?

Methods

Clinical Literature Search

We performed a clinical literature search on January 22, 2024, to retrieve studies published from database inception until the search date. We used the Ovid interface in the following databases: MEDLINE, Embase, the Cochrane Central Register of Controlled Trials, the Cochrane Database of Systematic Reviews, and the National Health Service Economic Evaluation Database (NHS EED).

A medical librarian developed the search strategies using controlled vocabulary (e.g., Medical Subject Headings) and relevant keywords. The final search strategy was peer-reviewed using the PRESS Checklist.[36]

We created database auto-alerts in MEDLINE and Embase, and monitored them until April 8, 2024. We also performed a targeted grey literature search of the International HTA Database, the websites of health technology assessment organizations and regulatory agencies, and clinical trial and systematic review registries, following a standard list of sites developed internally. See Appendix 1 for our literature search strategies, including all search terms.

Eligibility Criteria

Studies

Inclusion Criteria

- English-language full-text publications
- Studies published since inception
- Comparative studies (e.g., randomized controlled trials, diagnostic accuracy studies, observational studies)

- Systematic reviews and health technology assessments
  - We considered leveraging existing work, taking into account factors such as recency, quality, and relevance to the research question

Exclusion Criteria

- Noncomparative studies
- Editorials, commentaries, case reports, letters
- Animal and in vitro studies
- Studies using chest phantoms (an object designed to simulate the human body and to resemble the appearance of chest radiographs)
- Modelling studies

Participants

Inclusion Criterion

- Adults requiring chest radiography to detect conditions such as pneumonia, pneumothorax, pleural effusion, cavitation, or lung nodules, or to visualize lines, tubes, or implanted medical devices
  - Includes adults in ICU or ED receiving chest radiography as required for any of the conditions above or other conditions

Exclusion Criteria

- Children
- Adults receiving a chest radiography to diagnose conditions other than the ones listed above or receiving non-chest radiographies
- Adults receiving a chest radiography for lung cancer screening

Interventions

Inclusion Criteria

- Single-exposure, dual-energy subtraction (DES) digital flat panel x-ray detectors (or x-ray systems using these flat panel detectors) that generate both bone- and soft-tissue–subtracted x-ray images in addition to a conventional x-ray image
  - Used for chest radiography
  - Studies in which such devices were employed but only 1 of the subtracted images (bone or soft tissue) was used in decision-making/diagnosis
  - Detectors used in fixed or mobile digital x-ray systems

Exclusion Criteria

- Dual-exposure DES radiography (including dual-energy x-ray absorptiometry [DEXA])
- Single-exposure, DES radiography using computed radiography, e.g., using phosphorous plates

- Non-DES technologies (software, computer-aided detection [CAD], AI, or machine learning, etc.) that generate bone- and/or soft tissue–subtracted x-ray images
- Technologies that aim to enhance the quality of the x-ray image without using bone or soft tissue subtraction (e.g., software, AI, or machine learning, grey-scale inversion)
- Other types of imaging technologies and procedures, such as computed tomography, fluoroscopy, temporal subtraction, angiography, tomosynthesis, radiotherapy, etc.

Comparators

Inclusion Criteria

- Non-DES digital or computed chest radiography—fixed or mobile
  - May include the use of software, CAD, AI, machine learning, or other technology that aims to enhance the x-ray image quality with or without non-DES bone- or soft-tissue subtraction
- Dual-exposure, DES chest radiography
- Diagnostic accuracy reference standard: CT scanning

Outcome Measures

- Diagnostic accuracy: sensitivity and specificity
- Device malfunction, technical issues, or test failure
- Visualization of lines and tubes
- Radiologist and treating physician confidence in the diagnosis
- Treating physician confidence in the treatment decision
- Patient management, changes in treatment, or clinical outcomes
- Ability for treating physician to make a diagnosis or treatment decision without waiting for the radiology report
- Time between chest radiography and treatment decision or start of treatment
- Resource use, such as need for additional tests (imaging; e.g., CT scans) for diagnosis confirmation, follow-up, or repeat tests, and time taken to review the x-ray images
- Changes to exam workflow (steps necessary to carry out the test until the delivery of the report; e.g., patient positioning, radiation dose, image acquisition, etc.)
- Radiation dose

Literature Screening

Two reviewers screened titles and abstracts to assess the eligibility of a sample of 100 citations to validate the inclusion and exclusion criteria. A single reviewer then screened all remaining citations using Covidence[37] and obtained the full texts of studies that appeared eligible for review according to the inclusion criteria. The same reviewer then examined the full-text articles and selected studies eligible for inclusion. The reviewer also examined reference lists and consulted content experts for any additional relevant studies not identified through the search.

Data Extraction

We extracted relevant data on study characteristics and risk-of-bias items using a data form to collect information on the following:

- Source (e.g., citation information, study type)
- Methods (e.g., study design, study duration and years, participant allocation, allocation sequence concealment, blinding, reporting of missing data, reporting of outcomes, whether the study compared two or more groups)
- Outcomes (e.g., outcomes measured, number of participants for each outcome, number of participants missing for each outcome, outcome definition and source of information, unit of measurement, upper and lower limits [for scales], time points at which the outcomes were assessed)

We contacted study authors to provide clarification as needed.

Equity Considerations

Potential equity issues related to the use of single-exposure, DES flat panel x-ray detectors in the population of interest were not evident during scoping. We sought to report the available characteristics of participants in the included studies according to the PROGRESS-Plus categories;[35] however, the information was not provided in the studies.

Statistical Analysis

The study results were reported as provided in the studies. We did not perform a quantitative synthesis as we did not identify more than 1 study that reported on the same outcome.

Critical Appraisal of Evidence

We assessed risk of bias using the QUADAS-C tool[38] (Appendix 2).

We evaluated the quality of the body of evidence for each outcome according to the *Grading of Recommendations Assessment, Development, and Evaluation* (GRADE) *Handbook*.[39] The body of evidence was assessed based on the following considerations: risk of bias, inconsistency, indirectness, imprecision, and publication bias. The overall rating reflects our certainty in the evidence.

Results

Clinical Literature Search

The clinical literature search yielded 1,058 citations, including grey literature results and after removing duplicates, published from database inception to January 22, 2024. We identified 1 additional eligible study from other sources, including database alerts (monitored until April 8, 2024). In total, we identified 2 studies (both observational) that met our inclusion criteria.

The World Health Organization (WHO) 2021 Compendium of Innovative Health Technologies for Low-Resource Settings, COVID-19 and other health priorities,[40] included the Reveal 35C single-exposure, DES flat panel x-ray detector; however, since the document is based on information provided by the manufacturer rather than published studies, the publication wasn't included in our review. See Appendix 3 for a list of selected studies excluded after full-text review. Figure 1 presents the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA)[41] flow diagram for the clinical literature search.

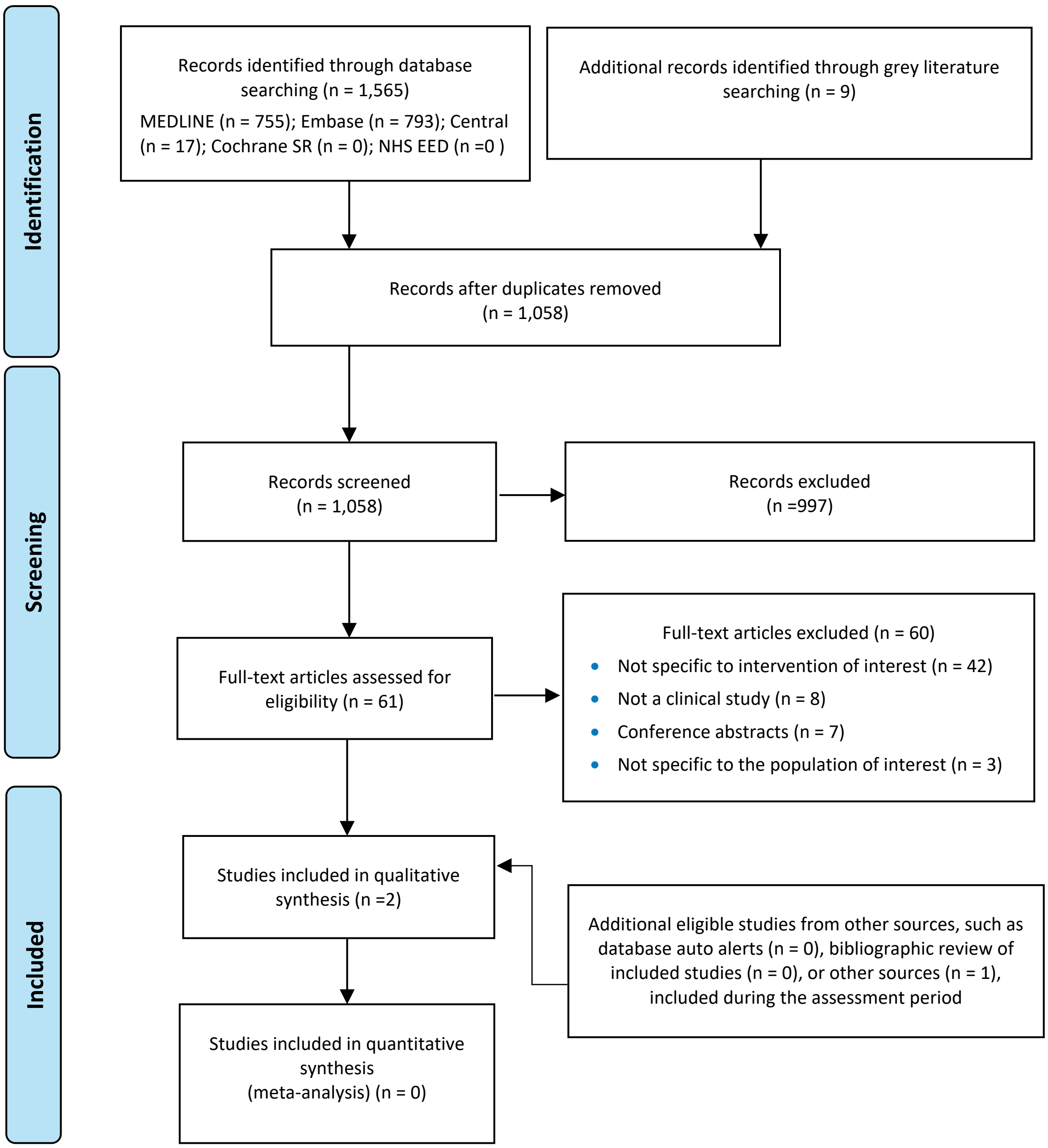

Figure 1: PRISMA Flow Diagram – Clinical Systematic Review

PRISMA flow diagram showing the clinical systematic review. The clinical literature search yielded 1,058 citations, including grey literature results and after removing duplicates, published between database inception and January 22, 2024. We screened the abstracts of the 1,058 identified studies and excluded 997. We assessed the full text of 61 articles and excluded a further 60. In the end, we included 2 articles in the qualitative synthesis.

Abbreviation: PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses.

Source: Adapted from Page et al.[41]

Characteristics of Included Studies

Study on the Likelihood of Detection of Different Conditions and Visibility of Lines and Tubes

One prospective study evaluated the use of single-exposure, DES bone and soft tissue x-ray images in addition to the conventional x-ray image for different indications.[42] Both the single-exposure, DES bone and soft tissue x-ray images and the conventional x-ray image were obtained using a single-exposure, DES digital flat panel x-ray detector (SpectralDR, KA Imaging, Waterloo, ON).[42]

Nine reviewers with different levels of experience reviewed the conventional and single-exposure, DES x-ray images.[42] The reviewers graded the likelihood of pneumonia, pneumothorax, bone fractures, pulmonary nodules, and the visibility of the tip of lines and tubes.[42] Other outcomes included diagnostic confidence and time to review the conventional and single-exposure, DES x-ray images.[42]

The study included 28 consecutive chest x-rays obtained in an ICU[42]—the patient characteristics were not provided in the publication. Additional details are provided in Appendix 4.

Study on Detection of Lung Nodule Calcification

A retrospective study evaluated whether using a single-exposure, DES soft tissue x-ray image in addition to the conventional x-ray image improved the differentiation between calcified and noncalcified pulmonary nodules compared with using only the conventional x-ray image.[21] Both the single-exposure, DES soft tissue x-ray image and the conventional x-ray image were obtained using a single-exposure, DES digital flat panel x-ray detector (Fujifilm DR Calneo Dual, Fujifilm).

Five radiologists with varying degrees of experience reviewed the chest x-ray images to evaluate the presence of calcification.[21] Computed tomography (CT) scanning was used as the reference standard for nodule calcification.[21]

The hospital radiology database was retrospectively searched for patients who received a chest radiography between January 2019 and March 2020 and whose radiology report included the word "nodule."[21] Eligible patients received a standing position, posteroanterior chest radiography using a single-exposure, DES flat panel x-ray detector to obtain a conventional and a single-exposure, DES soft tissue x-ray image; the chest radiography had to be performed within 3 months of a CT scan.[21] Patients with duplicate examinations, pulmonary nodules greater than 3 cm, more than 3 pulmonary nodules, or unclear pulmonary nodules on the x-ray were excluded from the study.[21]

Patient selection and eligibility assessment was based on the reading of the CT scan image by a radiologist with 5 years of experience and confirmed by a second radiologist with 18 years of experience—neither of these radiologists participated in the study; i.e., neither reviewed the single-exposure conventional and DES x-ray images.[21]

The outcomes for this retrospective study included sensitivity, specificity, diagnostic accuracy (true positive plus true negative results), misdiagnosis (false positive plus false negative results) of pulmonary nodule calcification, and inter-observer agreement among the 5 x-ray image reviewers (measured using Fleiss' kappa).[21] Additional details are provided in Appendix 4.

Among 688 patients identified through the hospital's database, 139 patients with 155 pulmonary nodules met the eligibility criteria and were included in the study.[21] Among these patients, 77 (55.4%) were male and the median age was 72 years.[21] A total of 48 (31.0%) nodules were calcified and 107 (69.0%) were noncalcified. Most nodules were located in the lungs (i.e., 30 [62.5%] and 102 [95.3%] calcified and noncalcified nodules, respectively); the remainder were located on the thoracic wall or skin.[21] Additional details are provided in Appendix 5.

Risk of Bias in the Included Studies

The risk of bias in 1 of the studies was considered unclear.[42] The study included consecutive x-ray images and the images were anonymized.[42] No information was provided regarding patient eligibility criteria, the number of patients screened, or how many were excluded from the study; the characteristics of the included patients and the scale used to rate the outcomes were not provided.[42]

The risk of bias in the second study was considered low as the x-ray images were reviewed without knowledge of the patients' diagnoses and all eligible patients were included in the analyses.[21] The actual time lag between the chest radiography and the reference standard was not reported by the authors, so it is difficult to determine if this would have affected the risk of patient misclassification.[21] See Appendix 2 for additional details.

Diagnostic Accuracy

One study evaluated the sensitivity, specificity, and accuracy of detecting pulmonary nodule calcification with the use of single-exposure, DES soft tissue and conventional x-ray images compared with the conventional x-ray image alone.[21] The conventional and DES x-ray images were obtained using a single-exposure, DES digital flat panel x-ray detector.[21]

Five reviewers with 3 to 26 years of experience evaluated the presence of calcification using a rating scale ranging from 1 (definitely calcified) to 5 (definitely not calcified); nodules rated as 1 or 2 were considered calcified whereas nodules rated 3 to 5 were considered noncalcified.[21] CT scanning was used as the reference standard.[21]

The conventional x-ray image was evaluated first, followed by the conventional and the single-exposure, DES soft tissue x-ray images 4 weeks later.[21] The x-ray images were evaluated without referring to the clinical information or CT scan images, but the location of the nodules on the x-ray image was provided to the reviewers.[21] The sensitivity to detect pulmonary nodule calcification ranged from 35.4% to 79.2% with the conventional x-ray image alone and 62.5% to 83.3% with the use of the single-exposure, DES soft tissue plus conventional x-ray images, depending on the reviewer (Table 1). The specificity ranged from 56.1% to 99.1% when reading the conventional x-ray image alone and 83.2% to 99.1% with the use of the single-exposure, DES soft tissue plus conventional x-ray images, depending on the reviewer (Table 1).[21]

The study results showed an improvement in the sensitivity to detect pulmonary nodule calcification for all reviewers with the use of the single-exposure, DES soft tissue plus conventional x-ray images compared with the conventional x-ray image alone, but the difference was only statistically significant for 2 of the 5 reviewers (who had 6 and 8 years of experience).[21]

The specificity to detect pulmonary nodule calcification remained the same for 1 reviewer, was slightly lower for another (difference not statistically significant), and improved for 3 reviewers (statistically significant for the reviewers with 3 and 8 years of experience) with the use of the single-exposure, DES soft tissue plus conventional x-ray images compared with the conventional x-ray image alone.[21] Details are provided in Table 1.

A subgroup analysis evaluating the number of true positive and true negative results according to nodule diameter showed a similar trend (Appendix 6).[21]

Table 1: Sensitivity and Specificity to Detect Pulmonary Nodule Calcification

Reviewer (experience)[a]	Conventional x-ray[b]	Single-exposure, DES soft tissue plus conventional x-ray images[b]	*P* value
Reviewer 1 (26 y)	Sensitivity: 68.8%	Sensitivity: 77.1%	.21
	Specificity: 99.1%	Specificity: 99.1%	1.00
Reviewer 2 (14 y)	Sensitivity: 56.3%	Sensitivity: 62.5%	.51
	Specificity: 95.3%	Specificity: 99.1%	.10
Reviewer 3 (8 y)	Sensitivity: 58.3%	Sensitivity: 77.1%	.02
	Specificity: 88.8%	Specificity: 99.1%	.002
Reviewer 4 (6 y)	Sensitivity: 35.4%	Sensitivity: 70.8%	< .001
	Specificity: 96.3%	Specificity: 94.4%	.48
Reviewer 5 (3 y)	Sensitivity: 79.2%	Sensitivity: 83.3%	.53
	Specificity: 56.1%	Specificity: 83.2%	< .001

Abbreviation: DES, dual-energy subtraction.
[a]The reviewers were numbered 1 through 5 according to the study publication.[21]
[b]N = 155 pulmonary nodules: 48 calcified and 107 noncalcified.
Source: Minato et al.[21]

The inter-observer agreement among the 5 reviewers was 0.334 (fair agreement [using the Fleiss kappa statistical measure]) with the use of the conventional x-ray image alone and 0.688 (substantial agreement [Fleiss kappa]) when the single-exposure, DES the soft tissue x-ray image was added.[21] The confidence intervals for the agreement measures were not provided.

The study also showed a decrease in the percentage of false positive and false negative results (fewer misdiagnoses) for pulmonary nodules overlapping with bones for all 5 reviewers with the addition of the single-exposure, DES soft tissue x-ray image compared with the conventional x-ray image alone; the difference was statistically significant for 2 reviewers (8 and 3 years of experience).[21] For nodules that didn't overlap with bones, the percentage of misdiagnoses with the use of the single-exposure, DES soft tissue plus conventional x-ray images compared with the conventional x-ray image alone didn't change for 1 reviewer, increased for another (not statistically significant), and decreased for the remaining 3 reviewers (statistically significant for the reviewer with 6 years of experience).[21] See Table 2 for additional information.

Table 2: Percentage of False Positive and False Negative Results According to Pulmonary Nodule Overlap with Bone

Reviewer (experience)[a]	Nodule overlapped with bone (N = 131)			Nodule did not overlap with bone (N = 24)		
	Conventional x-ray (%)	Single-exposure, DES soft tissue plus conventional x-ray images (%)	*P* value	Conventional x-ray (%)	Single-exposure, DES soft tissue plus conventional x-ray images (%)	*P* value
Reviewer 1 (26 y)	15 (11.5)	10 (7.5)	.096	1 (4.2)	2 (8.3)	.32
Reviewer 2 (14 y)	23 (17.6)	16 (12.2)	.14	3 (12.5)	3 (12.5)	1.00
Reviewer 3 (8 y)	28 (21.4)	10 (7.6)	< .001	4 (16.6)	2 (8.3)	.16
Reviewer 4 (6 y)	29 (22.1)	19 (14.5)	.05	6 (25.0)	1 (4.2)	.03
Reviewer 5 (3 y)	47 (35.9)	21 (16.0)	< .001	10 (41.7)	5 (20.8)	.06

Abbreviation: DES, dual-energy subtraction.

[a]The reviewers were numbered 1 through 5 according to the study publication.[21]

Source: Minato et al.[21]

The GRADE quality of the evidence was considered Low due to indirectness and imprecision (Appendix 2).

Visibility of Tips of Lines and Tubes

One study evaluated the visibility of the tips of lines and tubes with the use of single-exposure, DES bone and soft tissue x-ray images plus the conventional x-ray image compared with the conventional x-ray image alone using a 5-point scale.[42] The conventional and DES x-ray images were obtained using a single-exposure, DES digital flat panel x-ray detector.[42] Nine reviewers with different levels of experience (1 medical student, 4 residents, 1 fellow, 3 chest radiologists) participated in the study.[42]

The x-ray images were processed to remove annotations and to anonymize the images before being reviewed.[42] The reviewers first read the conventional x-ray image alone, which was followed by the review of the additional single-exposure, DES bone and soft tissue x-ray images 1 week later.[42] The patients' clinical history was not provided to the reviewers.[42]

This outcome was assessed in 14 patients: 10 with peripherally inserted central catheter (PICC) lines, 2 with a port system, and 2 with a tunnelled jugular catheter.[42] The study authors reported that all reviewers identified the tips of lines and tubes on the conventional x-ray image alone in all 14 patients, but 8 of 9 reviewers (*P* < .001) reported improved visibility with the addition of the single-exposure, DES bone and soft-tissue x-ray images.[42]

Information about the scale used to assess visibility and the results obtained by each reviewer were not provided. The GRADE quality of the evidence was considered Very low due to risk of bias, indirectness, and imprecision (Appendix 2).

Likelihood of Pneumonia, Pneumothorax, Bone Fractures, and Pulmonary Nodules

One of the studies stated that this outcome was evaluated,[42] but the authors did not provide results.

Diagnostic Confidence

One study evaluated the self-reported overall diagnostic confidence with the use of single-exposure, DES soft tissue and bone x-ray images plus the conventional x-ray image compared with the conventional x-ray image alone in patients hospitalized in the ICU.[42] The images were obtained using a single-exposure, DES digital flat panel x-ray detector.[42]

The x-ray image reviewers reported an increase in the overall diagnostic confidence for 16 of 28 patients (57.1%) with the use of single-exposure, DES bone and soft tissue x-ray images plus the conventional x-ray image compared with the conventional x-ray image alone.[42]

Information about the accuracy of the diagnoses, the results for each reviewer, and the patient conditions under evaluation were not provided. A reference standard was not used. The GRADE quality of the evidence was considered Very low due to risk of bias, indirectness, and imprecision (Appendix 2).

X-Ray Image Reading Time

One study reported that there was no statistically significant difference in the median total reading time between the use of single-exposure, DES bone and soft tissue x-ray images plus the conventional x-ray image compared with the conventional x-ray image alone, median 29.52 and 29.07 minutes, respectively ($P = .32$).[42] The images were obtained using a single-exposure, DES digital flat panel x-ray detector.[42]

No information was provided by the authors regarding the patient conditions under evaluation and the reading times for each reviewer. The GRADE quality of the evidence was considered Very low due to risk of bias, indirectness, and imprecision (Appendix 2).

Ongoing Studies and Conference Abstracts

We identified the protocol for an Ontario study evaluating the feasibility of a single-exposure, DES x-ray detector for the detection of pulmonary lesions compared with conventional radiography and CT scanning in patients with previously diagnosed carcinoma with lung metastases or a previously detected pulmonary nodule (NCT03528733).[43] According to the records on the United States National Library of Medicine clinical trials registry website,[43] the study was expected to be completed in June 2021. We were unable to identify the full-text publication of this study.

We are aware of the conference abstracts with single-exposure, DES flat panel x-ray detectors listed below. We have not identified full text publications of these abstracts. Given that the full study methodology and results are not provided in the conference abstracts, we have not reported their results.

- Chou PC, Karim, KS. Single-exposure dual-energy radiography for the subtraction of in-dwelling devices in the soft tissue image. Presented at the European Congress of Radiology, 2023 (Poster number C-15921).[44]
- Maurino SL, Karim KS, Venkatesh V, Tilley S. Diagnostic value of single-exposure, dual-energy subtraction radiography in lung lesion detection: initial results. Presented at the European Congress of Radiology, 2022 (Poster number C-15595).[45]

- Tijmes FS, Kandel S, May M, Ronghe S, Rogalla P. Diagnostic value of dual-energy chest x-ray in immunocompromised patients to rule out pneumonia: initial results. Presented at the European Congress of Radiology, 2021 (Abstract number RPS 504-3).[46]

Discussion

Our review identified 2 eligible studies that reported on the use of single-exposure, DES digital flat panel x-ray detectors in very specific indications—differentiation between calcified and noncalcified pulmonary nodules and visualization of the tips of lines and tubes.[21,42]

The findings of one of the studies suggest that the use of the single-exposure, DES soft tissue x-ray image in addition to the conventional x-ray image obtained using a single-exposure, DES flat panel x-ray detector may improve the reviewers' ability to distinguish between calcified and noncalcified pulmonary nodules compared to the conventional x-ray image alone (difference not statistically significant for 3 of the 5 reviewers).[21] According to the authors, less experienced radiologists saw greater improvement.[21]

The presence of calcification in pulmonary nodules suggests that it is a benign lesion[3,21,27] and the reference standard for its detection is CT scanning.[27] The study authors were unable to evaluate whether using single-exposure, DES flat panel x-ray detectors would allow the distinction between diffuse and partially calcified pulmonary nodules as they were unable to evaluate it separately in their study—the pattern of calcification in a pulmonary nodule, which they did not evaluate, is associated with the frequency of benignity and malignancy.[21]

In the second study, the x-ray reviewers were able to identify the tips of lines and tubes with the conventional x-ray image alone for all patients, but the authors stated that the visibility was improved with the addition of the single-exposure, DES bone and soft tissue x-ray images for most reviewers (details for individual reviewers was not provided).[42] The study also reported an increase in the x-ray image reviewers' self-reported diagnostic confidence in 57% of patients and a similar x-ray image review time with the use of the single-exposure, DES x-ray images plus a conventional x-ray image compared with a conventional x-ray image alone.[42] However, information about patient characteristics and the conditions under evaluation was not provided for these 2 outcomes (diagnostic confidence and review time).

Limitations

In the studies identified,[21,42] the conventional and the single-exposure, DES x-ray images were obtained simultaneously using the same single-exposure, DES flat panel detector. There was no comparison with other commercially available x-ray systems and technologies that aim to enhance the quality of the x-ray image—this affects the generalizability of the study results.

Of the 2 studies, only 1[21] provided details about the patient population and the scale used to assess the outcomes. Further, the studies evaluated a limited number of indications. Evidence of the diagnostic accuracy of single-exposure, DES flat panel x-ray detectors versus the conventional x-ray for the indications that are the focus of this review (pneumonia, lung nodules, pneumothorax, visualization of lines and tubes, etc.) has not been identified.

Moreover, the impact of the technology on outcomes such as patient management, clinical outcomes, resource use (e.g., need for additional imaging procedures, such as CT scanning), etc. compared with conventional x-ray was not assessed.

Conclusions

The use of the single-exposure, DES soft tissue x-ray image plus the conventional x-ray image obtained using a single-exposure, DES digital flat panel x-ray detector may lead to an improvement in the sensitivity and specificity to detect pulmonary nodule calcification compared with using the conventional x-ray image alone (GRADE: Low).

The evidence is very uncertain for the effect of using the single-exposure, DES soft tissue and bone x-ray images plus the conventional x-ray image obtained using a single-exposure, DES digital flat panel x-ray detector on the visibility of the tips of lines and tubes, diagnostic confidence, and time to review the x-ray images compared with using the conventional x-ray image alone (GRADE: Very low).

Our systematic literature review identified scarce evidence for the use of single-exposure, DES flat panel x-ray detectors compared with conventional x-ray for the populations and outcomes that we sought to evaluate. We did not identify any evidence for its impact on changes in patient management, clinical outcomes, need for other imaging procedures, among other outcomes, and the evidence on sensitivity and specificity was limited to a very specific indication. The studies identified did not compare the use of the technology under evaluation with other commercially available x-ray systems and technologies that aim to enhance the quality of the x-ray image, which affects the generalizability of the study results.

Economic Evidence

Research Question

What is the cost-effectiveness of single-exposure, dual-energy subtraction x-ray flat panel detectors used for chest radiography in adults to detect conditions such as pneumonia, cavitation, pleural effusion, pneumothorax, or pulmonary nodules, and to visualize lines, tubes, catheters, or implanted medical devices?

Methods

Economic Literature Search

We performed an economic literature search on January 22, 2024, to retrieve studies published from database inception until the search date. To retrieve relevant studies, we developed a search using the clinical search strategy with an economic and costing filter applied.

We created database auto-alerts in MEDLINE and Embase, and monitored them until June 2024. We also performed a targeted grey literature search following a standard list of websites developed internally, which includes the International HTA Database and the Tufts Cost-Effectiveness Analysis Registry. See Clinical Literature Search, above, for further details on methods used. See Appendix 1 for our literature search strategies, including all search terms.

Eligibility Criteria

Studies

Inclusion Criteria

- English-language full-text publications
- Cost–benefit analyses, cost-effectiveness analyses, cost-minimization analyses, or cost–utility analyses
- Comparative costing analysis

Exclusion Criteria

- Narrative or systematic reviews, letters/editorials, case reports, commentaries, abstracts, posters, unpublished studies

Participants/Population

Inclusion Criteria

- Adults requiring chest radiography to detect conditions such as pneumonia, pneumothorax, pleural effusion, cavitation, or lung nodules, or to visualize lines, tubes, catheters, or implanted medical devices

- Includes adults in ICU or ED receiving chest radiography as required for any of the conditions above or other conditions

Exclusion Criteria

- Children
- Adults receiving a chest radiography to diagnose conditions other than the ones listed above or receiving non-chest radiographies
- Adults receiving a chest x-ray for lung cancer screening

Interventions

Inclusion Criteria

- Single-exposure, dual-energy subtraction (DES) flat panel detectors (or x-ray systems using these flat panel detectors) that generate both bone- and soft-tissue–subtracted images in addition to a conventional x-ray image:
  - Used for chest radiography
  - Studies in which such devices were employed, but only 1 of the subtracted images (bone or soft tissue) was used in decision making/diagnosis
  - Detectors used in fixed or mobile digital x-ray systems
- Single-exposure, DES devices that can only be used in fixed rooms

Exclusion Criteria

- Dual-exposure DES radiography (including dual-energy x-ray absorptiometry [DEXA])
- Dual-exposure DES radiography using computed radiography flat panel detectors (e.g., using phosphorous plates)
- Devices (software, computer-aided detection [CAD], temporal subtraction, etc.) that allow only 1 type of subtracted x-ray image (bone or soft tissue) to be generated
- Non-DES technologies (software, computer-aided detection [CAD], AI, or machine learning, etc.) that generate bone- and/or soft tissue–subtracted x-ray images Technologies that aim to enhance the x-ray image without using bone or soft tissue subtraction (e.g., software, AI, or machine learning, grey-scale inversion)
- Other types of imaging techniques and procedures such as computed tomography (CT), fluoroscopy, angiography, tomosynthesis, on-board imaging, and radiotherapy, etc.

Comparators

Inclusion Criteria

- Non-DES digital or computed radiography—fixed or mobile

    - May include the use of software, CAD, AI, machine learning, or other technology that aims to enhance the x-ray image quality with or without using non-DES bone- or soft-tissue subtraction
- Dual-exposure, DES chest radiographs

Outcome Measures

- Costs
- Health outcomes (e.g., quality-adjusted life-years)
- Incremental costs
- Incremental effectiveness
- Incremental cost-effectiveness ratios

Literature Screening

A single reviewer conducted an initial screening of titles and abstracts using Covidence[47] and then obtained the full texts of studies that appeared eligible for review according to the inclusion criteria. The same reviewer then examined the full-text articles and selected studies eligible for inclusion. The reviewer also examined reference lists and consulted content experts for any additional relevant studies not identified through the search.

Data Extraction

We extracted relevant data on study characteristics and outcomes to collect information about the following:

- Source (e.g., citation information, study type)
- Methods (e.g., study design, analytic technique, perspective, time horizon, population, intervention[s], comparator[s])
- Outcomes (e.g., health outcomes, costs, incremental cost-effectiveness ratios)

Study Applicability

We determined the usefulness of each identified study for decision-making by applying a modified quality appraisal checklist for economic evaluations originally developed by the National Institute for Health and Care Excellence (NICE) in the United Kingdom.[48] The NICE checklist has 2 sections: the first is for assessing study applicability, and the second is for assessing study limitations. We modified the wording of the questions of the first section to make it specific to Ontario. Using this checklist, we assessed the applicability of each study to the research question (directly, partially, or not applicable).

Results

Economic Literature Search

The economic literature search yielded 80 citations, including grey literature results and after the removal of duplicates, published between database inception and January 22, 2024. We identified one additional eligible study from other sources, including database alerts (monitored until June 2024). In total, we identified 1 costing study that met our inclusion criteria. See Appendix 7 for a list of selected studies excluded after full-text review. Figure 2 presents the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA)[49] flow diagram for the economic literature search.

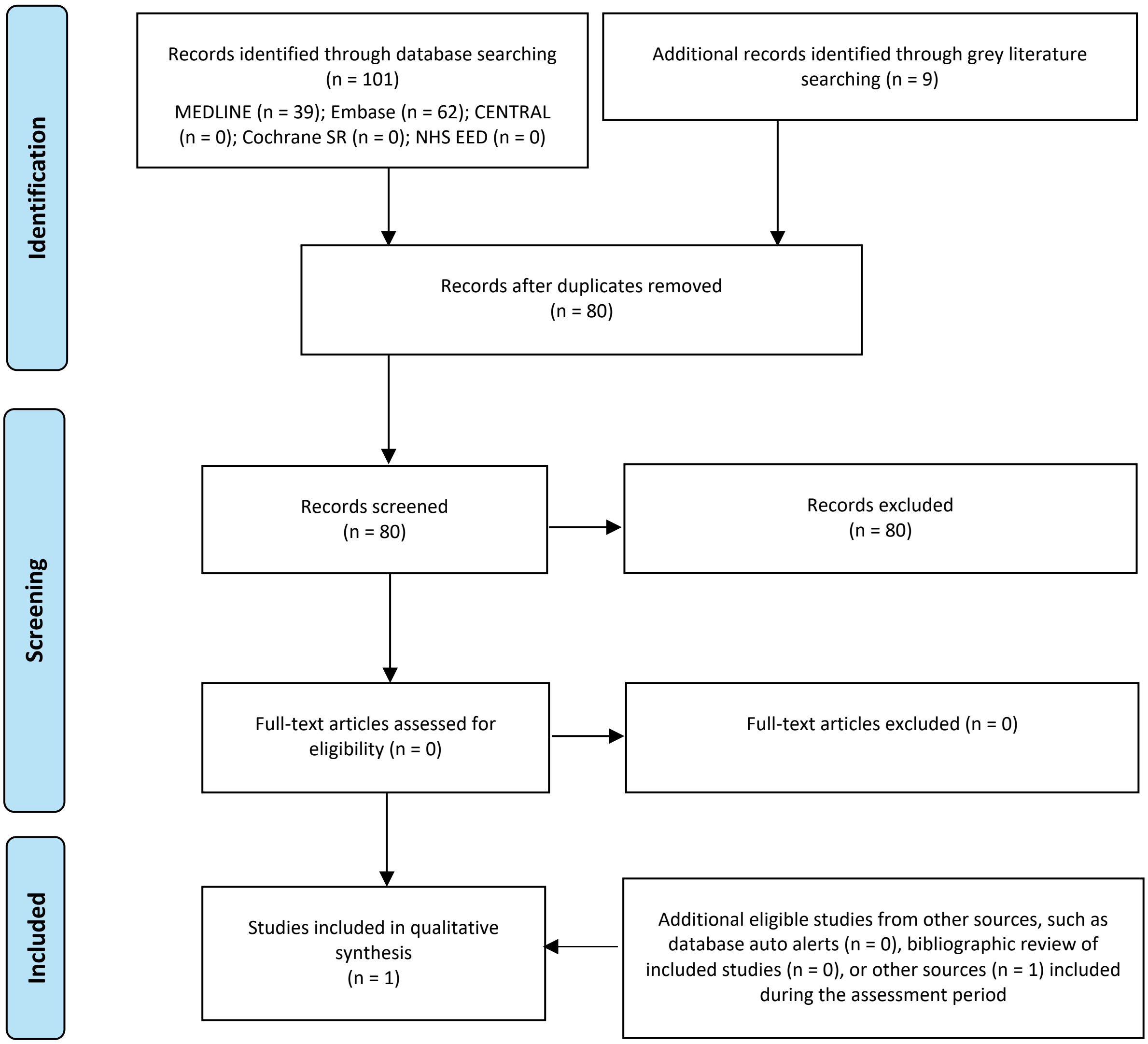

Figure 2: PRISMA Flow Diagram – Economic Systematic Review

PRISMA flow diagram showing the economic systematic review. The economic literature search yielded 80 citations, including grey literature results and after removing duplicates, published between database inception and April 2024. We screened the abstracts of the 80 identified studies and excluded all of them. We identified 1 additional study from the manufacturer. In the end, we included 1 article in the qualitative synthesis.
Abbreviation: PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses.
Source: Adapted from Page et al.[49]

Overview of Included Economic Studies

We identified 1 US costing analysis.[50] This analysis was conducted on a clinical site with at least 1 emergency and critical care facility, and it assumed a daily x-ray scan volume of 120 patients or fewer.[50] It considered the impact of single-exposure, DES x-ray imaging compared to a case in which the condition was not detected using standard digital x-ray imaging. The following outcomes were estimated: extra cases diagnosed annually, additional billings, cost savings due to non-reimbursed procedures, and potential malpractice costs avoided (defined as costs related to settlement and lawsuit).[50] The study authors concluded that, in a typical clinical site adopting DES x-ray for detecting conditions including pulmonary (lung) nodules, coronary calcium, pneumonia, and pneumothorax, 74 extra cases would be found annually. The additional detection of missed cases would result in additional costs of $530,000 USD, and a cost savings of $255,000 USD due to non-reimbursed procedures per year for this typical clinical site. This analysis also estimated that adoption of single-exposure, DES x-ray in a typical clinical site in the United States would lead to a $3.96 million savings due to avoided malpractice costs.[50]

Table 3: Characteristics of Studies Included in the Economic Literature Review

Author, year, country, intervention, comparator	Analysis				Study population (conditions)	Results	
	N	Technique	Approach or perspective	Time horizon		Health outcomes	Cost differences from the scenario of not adopting DES technology[a]
Karim, 2021,[50] United States	1 clinical site with daily x-ray scan volumn ≤ 120	Hypothetical costing analysis, no modelling	Hypothetical cost comparison	1 y	Pulmonary nodules, coronary calcium, pneumonia, pneumothorax	Projected extra cases found annually	Projected additional billings, cost savings due to nonreimbursed procedures, malpractice costs avoided (USD; cost year NR) No probabilistic or deterministic sensitivity analysis was conducted
Interevention: DES, single exposure x-ray detector			Unclear	—	—	Lung nodules: 12 Coronary calcium: 41 Pneumonia: 18 Pneumothorax: 3	Lung nodules • Additional billing: $120,000 • Additional cost due to nonreimbursed procedures: $0 • Difference in malpractice costs: −$3,528,000 Coronary calcium • Additional billing: $410,000 • Additional cost due to nonreimbursed procedures: $0 • Difference in malpractice costs: $0 Pneumonia • Additional billing: $0 • Additional cost due to nonreimbursed procedures: −$180,000 • Difference in malpractice costs: $0 Pneumothorax • Additional billing: $0 • Additional cost due to nonreimbursed procedures: −$75,000 • Difference in malpractice costs: −$429,750 Total • Additional billing: $530,000 • Additional cost due to nonreimbursed procedures: −$255,000 • Difference in malpractice costs: −$3,957,750
Comparator: No DES, single exposure		—		—	—	—	—

Abbreviations: DES, dual energy subtraction; NR, not reported.
[a]Negative values indicate cost savings or cost avoided.

Applicability and Limitations of the Included Studies

Appendix 7 provides the results of the quality appraisal checklist for economic evaluations applied to the included study. Only 1 study was included, and it was deemed not directly applicable to our research question. Although the study included the population, intervention, and comparator of interest, the study presented a simple cost analysis and did not report any methodological details such as data inputs or assumptions. It compared the hypothetical cost impact of adopting the single-exposure, dual-energy subtraction x-ray detector versus using standard digital x-ray imaging.

This study estimated the number of additional diagnoses for 4 conditions, and further evaluated the costs related to additional billings, non-reimbursed procedures, and potential malpractice costs avoided. There was no detailed information on the setting, which was described as "a typical clinical site with a daily x-ray scan volume of 120 or fewer" in the United States. However, this analysis used cost parameters from the US setting, such as malpractice costs and claim data, for certain conditions. These costs may not be relevant to the Ontario setting. The study also did not include the cost of the single exposure DES x-ray technology itself.

Because this study was not directly applicable to our research question, we did not assess the study limitations. Notably, this report did not provide any methodological details and seemed to be hypothetical. Data inputs and assumptions were not reported, nor were sensitivity analyses conducted.

Discussion

We conducted an economic evidence review to identify relevant economic evaluations assessing the cost-effectiveness of single-exposure, DES flat panel x-ray detectors. We identified 1 costing study that met our inclusion criteria. However, it was not directly applicable to our research question and it was conducted in a US setting. The study also did not provide enough methodological details on how costs and effectiveness were estimated or a sensitivity analysis to examine the robustness of the results.[50] Therefore, the cost-effectiveness of single-exposure, DES flat panel x-ray detectors remains unknown.

Strengths and Limitations

We systematically searched electronic databases and grey literature sources and it is unlikely that any relevant published studies were missed. Nevertheless, we were limited in our conclusions about the cost-effectiveness of single-exposure, DES flat panel x-ray detectors by the paucity of evidence identified.

Conclusions

We identified 1 costing analysis in the US setting. This analysis suggested that adoption of single-exposure, DES flat panel x-ray detectors may lead to cost savings, cost avoidance, and additional billings due to improved diagnosis. However, the study was deemed not directly applicable to the Ontario setting. Therefore, the cost-effectiveness remains unknown.

Primary Economic Evaluation

Our economic evidence review did not identify any directly applicable economic studies. Therefore, the cost-effectiveness of single-exposure, DES flat panel x-ray detectors is unknown based on the published literature.

We are unable to conduct a primary economic evaluation due to limited clinical evidence to inform the development of a decision-analytic model. To estimate the cost-effectiveness of this technology (e.g., additional cost per additional correct diagnosis, or additional cost per quality-adjusted life year [QALY] gained), data on the diagnostic accuracy (e.g., sensitivity and specificity) of single-exposure, DES flat panel x-ray detectors versus the reference standard (e.g., CT scan) would be required for each indication. Our clinical evidence review identified 1 study,[51] suggesting that the use of the DES soft tissue x-ray imaging in addition to the conventional x-ray image may improve the reviewers' ability to distinguish between calcified and noncalcified nodules. However, this study was based on only 5 reviewers with different experience levels (from 3 to 26 years). In addition, there is limited clinical evidence on other potential benefits of this technology, such as the impact on the workflow (e.g., the treating physician may be able to make a diagnosis or treatment decision without waiting for the radiology report, or time needed for the radiologist to read the x-ray image),[10] health service utilization (e.g., reduce the need for CT), etc.[4] Another study found that although the self-reported diagnostic confidence by readers was improved, there may be no difference in reading time and there was no evidence for its impact on changes in patient management, patient outcomes, or need for other imaging procedures.[42]

It is difficult to estimate the impact of the technology on long-term costs and health outcomes since the population of interest is highly heterogenous.[14] Further, the usability of the technology across different settings (e.g., ER, ICU) is yet to be established. Consequently, it would be challenging to determine the costs and QALYs gained at the population level.

Owing to the limited evidence on the impacts of single-exposure, DES flat panel x-ray detectors on diagnostic accuracy, workflow, and health service utilization, and the challenges in estimating the impacts on long-term costs and health outcomes, we did not conduct a primary economic evaluation.

Budget Impact Analysis

Research Question

What is the potential 5-year budget impact from an Ontario institution perspective of purchasing single-exposure, DES flat panel x-ray detectors used for chest radiography in adults to detect conditions such as pneumonia, cavitation, pleural effusion, pneumothorax, or pulmonary nodules, and to visualize lines, tubes, catheters, or implanted medical devices?

Methods

Analytic Framework

We estimated the budget impact of adopting single-exposure, DES flat panel x-ray detectors using the cost difference between 2 scenarios: (1) current clinical practice without adopting the detectors (the current scenario) and (2) anticipated clinical practice with adopting the detectors (the new scenario). We conducted this budget impact analysis from an institutional perspective and estimate the additional cost of purchasing and operating single-exposure, DES flat panel x-ray detectors for a typical Ontario hospital that is replacing or upgrading the existing x-ray detectors. Figure 3 presents the budget impact model schematic.

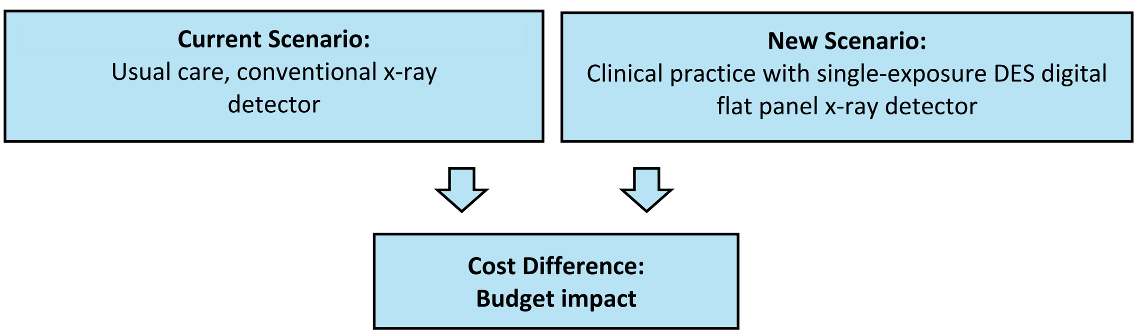

Figure 3: Schematic Model of Budget Impact

Flow chart describing the model for the budget impact analysis. The current scenario would explore resource use and total costs without adopting single-exposure, DES flat panel x-ray detectors. The new scenario would explore resource use and total costs adopting single-exposure, DES flat panel x-ray detectors. The budget impact would represent the difference in costs between the two scenarios.

Key Assumptions

- Introducing single-exposure, DES flat panel x-ray detectors to a hospital would not substantially change the total volume of people needing x-ray scans
- The diagnostic performance of chest radiography using single-exposure, DES flat panel x-ray detectors is similar to using conventional x-ray scans and the impact of this DES detector on working flow and process is negligible
- X-ray scans conducted with single-exposure, DES flat panel x-ray detectors are billed using the same physician billing code as for conventional x-ray scans[52,53]

- Hospitals would purchase single-exposure, DES flat panel x-ray detectors for their existing mobile x-ray devices. Our reference case considered the budget for this adoption strategy. Alternatively, we also conducted scenario analyses for other adoption strategies: 1) purchasing DES detectors for all fixed or mobile chest radiography devices, or 2) purchasing mobile x-ray devices with DES detectors
- The reference case considered the potential need for a community hospital to replace its x-ray detector. We assumed that this hospital has 3 mobile x-ray machines and they would buy 3 single-exposure, DES flat panel x-ray detectors for replacement. Our scenario analyses considered larger academic hospitals to replace x-ray detectors, and diagnostic clinics or long-term care homes to purchase new x-ray machines
- Single-exposure, DES flat panel x-ray detectors are compatible with existing mobile x-ray devices, and the additional cost of retrofitting is negligible
- The costs associated with changes in radiation exposure is negligible
- The lifetime of a single-exposure, DES flat panel x-ray detector exceeds 5 years and there will be no need for replacement over the 5-year time horizon considered in this analysis[54]

Adoption Scenario of Interest

Hospitals are the target setting for single-exposure, DES flat panel x-ray detectors. Currently, fixed or mobile x-rays detectors are available in hospitals. The single-exposure, DES flat panel x-ray detectors might be particularly useful with mobile x-ray devices in several places, including the emergency department, inpatient units, and intensive care units. The population of interest is adults who require chest radiography for possible pneumonia, pneumothorax, or lung nodules, and adults for whom the physicians need to visualize lines, tubes, and catheters. These patients typically present in a hospital setting.

We assumed a large community hospital needs 3 mobile x-ray devices. However, the need for x-ray devices differs depending on the type of hospital. In Ontario, academic or teaching hospitals are generally larger and have a larger need for diagnostic devices.

Current Intervention Mix: Purchasing Conventional X-Ray Detectors

Presently, a few Ontario hospitals use the Reveal 35C x-ray detector by KA Imaging to visualize lung nodules, diagnose conditions such as pneumonia and pneumothorax, and visualize lines and tubes. The detectors have been integrated in fixed and mobile x-ray devices.[55] The detectors were not purchased by these hospitals, but were provided by the manufacturer for evaluation purposes (Karim S. Karim, PhD, email communications, September 2023 to February 2024) as they are still in the pilot testing stage. However, most Ontario hospitals and clinics use conventional x-ray detectors with either fixed or mobile x-ray devices. Therefore, for the current scenario, we assume that a typical Ontario hospital currently uses 3 mobile x-ray devices with conventional detectors from other manufacturers.[56] There are different options for hospitals and clinics to choose from.

New Intervention Mix: Purchasing Single-Exposure, DES Flat Panel X-Ray Detectors

For the new scenario, we assumed that the single-exposure, DES flat panel x-ray detectors would be introduced gradually to Ontario hospitals. A typical Ontario hospital may purchase 3 detectors as their option for replacement or upgrade.

Resources and Costs

Cost inputs were obtained from Ontario sources, published literature,[56,57] and the manufacturer.[55] The analysis included the cost of the single-exposure, DES flat panel x-ray detectors and of the mobile x-ray devices. The costs related to warranty, training, technical support, and maintenance required to operate the devices were the same as those related to conventional detectors (Karim S. Karim, PhD, email communication, February 26, 2024). Thus, these costs were excluded from this analysis. We also did not include costs related to the subsequent health service use, such as diagnostic work-up or treatment, nor health outcome–related costs, given the limited clinical evidence and heterogeneous patient population. Our clinical evidence review identified 1 study (Rogalla et al[42]) reporting that there was no statistically significant difference in the median total reading time between the conventional x-ray image and the DES images (29.07 and 29.52 minutes, respectively).

According to a market report, the price of wireless flat panels (14 × 17 inches in size) ranged from $54,004 to $67,505 in 2024 CAD ($40,000 to 50,000 USD),[57] and the price of intermediate x-ray devices ranged from $87,757 to $120,159 CAD ($65,000 to $89,000 USD).[56] In our analysis, we used the mean value of $60,755 and $103,958 as the price of conventional detectors and x-ray devices, respectively (Table 4). According to the manufacturer, the mean price of 2 types of detectors was $64,800, which we used as the price of single-exposure, DES flat panel x-ray detectors. We estimated that the price for mobile x-ray devices with single-exposure, DES detectors was $106,650 (average price of 2 models: Reveal Mobi Pro and Reveal Mobi Lite) (Karim S. Karim, PhD, email communication, February 26, 2024).

We assume that there would be no change to the billing codes (e.g., X090, X091, and X092 for chest radiography)[53] and that using either single-exposure, DES flat panel x-ray detectors, or conventional x-ray detectors would not differ in charges.

Table 4: Cost information in this budget impact analysis

Device and service	Cost estimate	Source
Single-exposure, DES flat panel detector: detector only	$64,800 (average price of 2 products)	Email communication: Karim S. Karim, PhD, February 26, 2024
Conventional detector	$60,755	Block Imaging price guide[57]
Single-exposure, DES flat panel detector, mobile x-ray device (x-ray machine with detector)	$106,650 (average price of 2 products)	Email communication: Karim S. Karim, PhD, February 26, 2024
Conventional mobile x-ray machine	$103,958	Block Imaging price guide[56]

Abbreviation: DES, dual energy subtraction.

Internal Validation

The secondary health economist conducted formal internal validation. This process included testing the mathematical logic of the model, checking for errors, and ensuring the accuracy of parameter inputs and equations.

Analysis

We conducted a standalone budget impact reference case analysis and sensitivity analysis (i.e., scenario analyses). Our reference case represents the analysis with the most likely set of input parameters and model assumptions. Our scenarios explored how the results are affected by varying the cost of the device. Table 5 summarizes the different settings and scenarios to which this budget impact analysis may be relevant.

Scenario 1: Adoption of X-Ray Devices

The reference case considered the budget impact for a community hospital and assumed that a single community hospital would purchase single-exposure, DES flat panel detectors and upgrade existing x-ray devices. This scenario examined an alternative approach involving the purchase of 3 new mobile x-ray devices with single-exposure, DES flat panel detectors as the adoption strategy.

Scenario 2: Large Hospital or Hospital With Larger Need for Diagnostic Device

This scenario evaluated the impact of adopting this technology in a large hospital (e.g., with a capacity larger than 700 hospital beds), or a teaching or academic hospital with a larger need for diagnostic services.

Scenario 3: Clinic

This scenario evaluated the impact of adopting this technology in different settings, such as clinics. We defined a clinic as a health care center where people receive routine preventative care when they are healthy or are seen by a doctor or primary care provider when they are sick. Compared with people who visit hospitals, people who visit a clinic are generally less sick or injured and do not stay overnight.

Scenario 4: Long-Term Care Home

This scenario evaluated the impact of adopting the mobile x-ray devices with single-exposure, DES flat panels by long-term care homes. Due to similar limitations in evidence about the effects of DES on diagnostic outcomes and workflow, we were unable to quantify any potential downstream benefits of introducing this technology in the long-term care home setting. However, we assumed that in a long-term care home, there are health workers who are capable of using the mobile x-ray devices and there would be no additional costs related to hiring more health workers.

Scenario 5: Province-Wide Adoption

This analysis adopts the perspective of hospitals or clinics during the replacement or upgrade of existing x-ray machines. According to the X-Ray Inspection Service of the Ontario Ministry of Health, there were 2,233 and 953 x-ray devices for diagnosis purpose in Ontario hospitals and clinics, respectively, in 2017 (Ontario Ministry of Health, email communication, February 22, 2024). Assuming that the number of x-ray devices would be constant and that each year 10% of the devices would need detector replacement, we estimated that 319 detectors would be purchased by Ontario hospitals and clinics annually. According to the market report, the flat panels take 44% of the x-ray detector market share.[57] We estimated that Ontario hospitals and clinics need 141 flat panel detectors annually. We assume a gradual increase in the share of single-exposure, DES flat panel detectors of 10% each year over the next 5 years (from 30% in year 1 to 70% in year 5).

Table 5: Scenarios of Technology Adoption

Scenario	Setting	DES detector only	X-ray device, including DES detector
Reference case	Community hospital	3	0
Scenario 1	Community hospital	0	3
Scenario 2	Academic hospital	5	0
Scenario 3	Diagnostic clinic	1	0
Scenario 4	Long term care	0	1
Scenario 5	Province-wide adoption	Year 1: 42 Year 2: 56 Year 3: 70 Year 4: 84 Year 5: 98	0

Abbreviation: DES, dual energy subtraction.

Results

Reference Case

Table 6 presents the budget impact of purchasing single-exposure, DES flat panel detectors or x-ray devices with this type of detector from an institutional perspective. For the reference case, we assumed a hospital would buy 3 single-exposure, DES flat panel detectors to retrofit the available mobile x-ray devices. The cost was estimated to be $194,400, compared with $182,264 for 3 conventional flat panel detectors; this would lead to additional costs of $12,137 in year 1, and no impact in the following years.

Table 6: Budget Impact Analysis Results[a]

Setting	Current scenario	New scenario	Budget impact
Community hospital, purchasing 3 single exposure DES flat panel detectors to retrofit existing x-ray devices	$182,264	$194,400	$12,137

Abbreviations: DES, dual energy subtraction.
[a]Costs in 2024 CAD.
[c]Results may appear inexact due to rounding.

Scenario Analysis

As expected, price was a key parameter for budget impact. When the price of detectors decreased by 10%, purchasing 3 detectors to retrofit available x-ray machines would lead to a cost-savings of $7,304 (reference case: $12,137), compared to purchasing 3 conventional detectors. In contrast, if the price were 10% higher, the budget impact would be an additional $31,577 over the reference case.

Purchasing 3 mobile x-ray devices would lead to an additional cost of $8,077 — $319,950 for mobile x-ray devices with single-exposure, DES flat panel detectors versus $311,873 for mobile x-ray devices with conventional detectors. The budget impact would be an additional $20,228 for five single-exposure, DES flat panel x-ray detectors in the case of hospitals with a larger need for diagnostic devices.

Similarly, for a diagnostic clinic purchasing 1 detector to retrofit with an available mobile x-ray device, the budget impact was estimated to be an additional $4,046. For a long-term care home purchasing 1 mobile x-ray with single-exposure, DES flat panel detector, the budget impact would be an additional $2,692 over the cost of 1 conventional mobile x-ray device ($103,958).

Table 7: Budget Impact Analysis Results[a]

Setting	Current scenario	New scenario	Budget impact
Community hospital purchasing 3 mobile x-ray devices (Scenario 1, reference case)	$311,873	$319,950	$8,077
Academic hospital purchasing 5 x-ray detectors (Scenario 2)	$303,773	$324,000	$20,228
Diagnostic clinic purchasing 1 x-ray detector (Scenario 3)	$60,755	$64,800	$4,046
Long-term care home purchasing 1 mobile x-ray device (Scenario 4)	$103,958	$106,650	$2,692

[a]Costs in 2024 CAD.

Adopting the technology at the provincial level (assuming a 30% uptake of the single-exposure, DES flat panel detectors in year 1, increasing to 70% in year 5) would lead to additional costs of about $0.17 million in year 1 to about $0.40 million in year 5 (Table 8). The total budget impact for this option over 5 years is about $1.42 million.

Table 8: Budget Impact Analysis Results for Province-Wide Adoption

Scenario	Budget impact, $ million[a]					
	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Current scenario	8.52	8.52	8.52	8.52	8.52	42.60
New scenario	8.69	8.74	8.80	8.86	8.91	44.00
Budget impact[b]	0.17	0.23	0.28	0.34	0.40	1.42

[a]Costs in 2024 CAD.

Discussion

This analysis aimed to estimate the budget impact of adopting single-exposure, DES flat panel detectors from the viewpoint of a single institution, such as a hospital or clinic. The budget impact depended on the purchase decision (e.g., detectors or x-ray devices) and the number of detectors or x-ray devices purchased. Our findings could potentially guide the distribution of budgets to hospitals or clinics opting for the purchase of detectors.

We conducted our analysis from an institutional perspective. Our analysis differs from the public payer perspective as it represents the budget impact for a hospital or clinic to purchase and adopt this technology, which is useful in decisions about allocation of global budget. Although the exact funding strategy may differ on a case-by-case basis, the purchase of equipment such as x-ray detectors, along with their depreciation costs, generally falls under the scope of the institution's global budget. Evaluating the budget impact of adopting single-exposure, DES flat panel x-ray detectors from a public payer perspective is challenging due to the lack of information on the replacement of x-ray detectors and devices at the provincial level. Nevertheless, we conducted an analysis assuming that there is a gradual uptake increase for this technology (from 42 to 98 single-exposure, DES flat panel detectors purchased from year 1 to year 5).

Our analysis did not include potential implementation costs such as training, maintenance, and technical support, which, based on our consultations (Karim S. Karim, PhD, email communication, February 26, 2024), are generally no different from other manufacturers or providers. We assumed that the detectors are compatible with existing x-ray devices, software, and other infrastructures, and that implementation does not incur additional costs. However, there may be technical difficulties or barriers that need to be explored in future studies. For example, long-term care homes may not have imaging capabilities and so adopting this technology may mean securing additional resources (e.g., licensed professionals, shielding, training, etc.). On the other hand, retrofitting available x-ray devices with the detectors may present an opportunity for cost saving compared with other strategies, such as purchasing new x-ray devices or installing a new x-ray room/system. Our analysis considered only the device cost and may be a simplified representation of the adoption of this novel technology. Due to lack of good quality evidence, our cost estimations and assumptions need to be interpreted with caution.

One major challenge in modeling the costs and outcomes of adopting this new technology is that it could be used in many different populations for many different indications (e.g., people suspected of pneumonia, pneumothorax, lung nodules, tuberculosis, and in the visualization of lines, tubes, and catheters) and the accuracy would need to be established for each of those groups so that its cost-effectiveness could be properly estimated for each patient population or indication. The usability of the technology across different settings (e.g., ED, ICU) also needs to be established so we can characterize the relationship between technology adoption and outcomes. The technology is still in its early stages of development and application and there is a paucity of evidence to substantiate or evaluate the expected costs and benefits. The potential benefits may differ across different comparators and application scenarios. To conduct clinically plausible cost-effectiveness analyses, evidence to inform the model input parameters related to potential benefits of this technology is needed.[58] Our analysis also highlights the need for more studies focusing on the diagnostic performance of this technology and its impact on patient management processes and outcomes.

Not all claimed benefits, even if realized, may inherently translate into cost implications. For instance, improved usability (e.g., increased confidence in imaging results or time savings in image reading) may not yield cost savings from the perspectives of hospitals or clinics.[59] Still, institutions and health care workers may place a high value on medical devices that result in improvements in the usability. There may also be intangible and hard-to-measure savings that escaped our analysis. Adoption of health technologies may also introduce other benefits in other sectors, such as the local economy, labour force, and future technology development. However, these benefits are beyond the scope of our evaluation.

Strengths and Limitations

Our analyses indicate the budget needed for institutions such as hospitals or clinics to adopt this new technology; they may be useful for hospital administrator's decision making when choosing flat panel detectors and devices from various available options. We conducted several analyses to represent the different adoption scenarios. However, our analyses are restricted by the assumptions and uncertainty in the parameter inputs that informed them. Consequently, we only considered the cost of purchasing the single-exposure, DES flat panel detectors or x-ray devices, and excluded implementation-related costs (training, technical support, and maintenance), and other cost implications relevant to patient management and health outcomes. Our analyses could not represent the budget impact from a provincial public payer perspective, nor complex application scenarios that often happen in the implementation stage.

Conclusions

The lack of evidence on potential benefits to the diagnostic accuracy of chest x-rays using single-exposure, DES flat panel detectors, and the potential impact on patient management have introduced large uncertainty into the value of this new technology. Despite this uncertainty, when contextualized within the use of chest x-rays in the Ontario institutional setting, our analysis estimated that purchasing 3 detectors to retrofit with available x-ray machines may lead to an additional cost of $12,137. However, given the large degree of uncertainty around the costs and implications of this technology, our analyses are limited in their ability to represent the budget impact from a provincial public payer perspective or in complex application scenarios for Ontario institutions.

Health System Stakeholders' Perspectives

We engaged with health care providers to obtain perspectives on the use of the single-exposure, DES flat panel detector in Ontario and other relevant contextual issues.

Direct Provider Engagement

Methods

Partnership Plan

The partnership plan for this health technology assessment focused on engagements to examine the experiences of health care providers involved in conducting and interpreting x-rays in a clinical setting. We engaged with participants via video conference. We conducted qualitative interviews, as this method of engagement allowed us to identify relevant themes and explore their meaning in the experiences of health care providers conducting and interpreting x-rays.

Participant Outreach

We used an approach called purposeful sampling,[60-63] which involves engaging participants who are especially knowledgeable or experienced with the health technology under review. We also used snowball sampling to identify additional contacts from interview participants and Ontario Health. Participants, including radiologists, intensivists, x-ray technologists, and other experts in diagnostic medicine had a mix of experiences with the single-exposure, DES flat panel x-ray detector. Those with experience had used the Reveal 35C single-exposure, DES flat panel detector.

Inclusion Criteria

We sought to interview a variety of health care providers located at hospital sites across Ontario who may be familiar with the use of x-ray systems, including single-exposure, DES flat panel x-ray. Participants did not need to have had direct experience with single-exposure, DES flat panel x-ray detectors.

Exclusion Criteria

We did not set exclusion criteria for participants who otherwise met the inclusion criteria.

Approach

At the beginning of the interview, we explained the role of our organization and the purpose of this health technology assessment. The interviews lasted approximately 30 to 60 minutes. The interview was semi structured and consisted of a series of open-ended questions (see Interview Guide, Appendix 9). The objective was to gain further contextual information about x-ray diagnostic imaging in Ontario and provider perspectives on the use and non-use of single-exposure, DES flat panel x-ray detectors in a health care setting.

Data Extraction and Analysis

We used a modified version of a grounded-theory methodology to analyze our interview notes. The grounded theory approach allowed us to organize and analyze experiences across participants and identify relevant themes about the technology and its use. This method consists of a repetitive process of obtaining, documenting, and analyzing responses while simultaneously collecting, analyzing, and comparing information.[64,65] We used the qualitative data analysis software program NVivo[66] to identify themes in the data.

Results

Retrofitting Existing X-Ray Systems

Participants identified the need to retrofit existing x-ray systems to allow for the use of single-exposure, DES flat panel x-ray detector. There were 2 different types of x-ray systems that needed retrofitting: (1) fixed x-ray machines, and (2) mobile x-ray machines. Participants reported a variety of considerations in choosing an approach to adopting the technology.

Retrofitting a fixed x-ray machine requires an x-ray room equipped with a removable detector. A wall stand is needed to hold the detector in a fixed x-ray machine, and a grid is used to enhance the x-ray image. Incompatibilities in the single-exposure, DES flat panel x-ray detector with the wall stand and grid necessitates the purchase of new equipment, which is funded by the DES detector manufacturer (there is no direct cost to the facility). Additionally, a laptop is needed to use the single-exposure, DES flat panel x-ray detector software. Retrofitting a mobile x-ray machine requires the use of a separate tablet to view the images produced. Participants mentioned the lack of space on the mobile x-ray machine to place this tablet when moving it around the hospital. Additionally, consistent connectivity between the single-exposure, DES flat panel x-ray detector and the tablet is required, necessitating the use of a router. Connecting this router to the mobile x-ray machine risks having its warranty voided by the manufacturer. Because of this, an alternate router positioning is needed.

Participants shared that support was provided by the DES detector manufacturer for the retrofitting process and troubleshooting. Retrofitting the single-exposure, DES flat panel x-ray detector technology into a fixed or mobile x-ray machine was perceived to take more time than anticipated, though the issues were resolved.

DES Detector Physical Specifications

Currently, there is 1 standard size of the single-exposure, DES flat panel x-ray detector available (14 × 17 inches). Participants reported that the standard-sized detector produced quality x-ray images, with some image quality issues identified in x-rays done on larger patients. Participants expressed a benefit in having a larger-sized detector for larger patients (17 × 17 inches). There were differing opinions on heaviness of the single-exposure, DES flat panel x-ray detectors (these perceptions were based on weight of the detector previously used). There were concerns raised over ergonomics issues and strain the operator might face with using these detectors.

Battery Life

People we interviewed reported experiencing a 3–4–hour battery life with the single-exposure, DES flat panel x-ray detector , compared to about 8 hours for conventional detectors. This shorter battery life resulted in the single-exposure, DES flat panel x-ray detector needing to be recharged more frequently.

Additionally, the tablet required for the mobile x-ray machine needed recharging separately, which required planning and coordination.

Connectivity

All participants reported that the hospital Wi-Fi connection could be unreliable at times. This unreliable connection led to connectivity issues between the tablet/laptop and the single-exposure, DES flat panel x-ray detector. It was mentioned that if the distance between the tablet and router exceeded 1.5 meters, the connection was lost. It should be noted that there are also connectivity issues with the conventional detectors, but participants mentioned that they experienced more issues relating to connectivity with the single-exposure, DES flat panel x-ray detector compared to detectors from other manufacturers.

Image Quality

All participants who had experience viewing and interpreting the images produced by the single-exposure, DES flat panel x-ray detector reported that the images produced were comparable to or better than the images produced by conventional x-ray machines. In some cases, it was suggested that the images increased the confidence of those interpretating the x-ray in making a diagnosis. It was hypothesized that this increase in confidence may negate the need for a radiology consult in some cases. It was noted that the images produced could provide a greater benefit to inexperienced users compared to experienced users. The bone (soft–tissue subtracted) and the soft tissue (bone-subtracted) images produced provided more information and details, but this additional information may not be needed in all cases. Image quality from the single-exposure, DES flat panel x-ray detector was reduced in larger patients and in some cases the soft tissue images contained internal components of the detector.

User Interface of Application

There were different perspectives regarding the user friendliness of the software application interface. It was noted that there was a learning curve to become familiar with the interface. Other issues include difficulties with post processing tasks such as reordering and reassigning the image to another demographic.

Durability

Participants using the single-exposure, DES flat panel x-ray detector did so for only a short period of time. No issues were identified with respect to durability, but they could not speak to the long-term durability of the detector.

CT Scan Avoidance

There was broad consensus that the single-exposure, DES flat panel x-ray detector is not a replacement for a CT scan. Some participants hypothesized that the increased confidence in the DES x-ray image may reduce the need for a CT confirmation in some cases; however, there was general uncertainty regarding this.

Workflow

A separate laptop or tablet is required with the single-exposure, DES flat panel x-ray detector. Those using the detector in a mobile x-ray system noted the lack of a placement area for the tablet. This lack of a dedicated place for the tablet made it difficult to maneuver the system throughout the hospital, as well as created a need to find a place to rest the tablet when conducting the x-ray. Other problems included the small screen size on the tablet, which made it difficult to select certain icons within the software application, the need to charge the tablet separately from the detector, and the short (3–4 hour) battery life of the single-exposure, DES flat panel x-ray detector (compared to 8 hours for detectors from other manufacturers).

Participants who used the laptop in a fixed x-ray machine mentioned the inconvenience of having to go back and forth when inputting information between the laptop dedicated to the single-exposure, DES flat panel x-ray detector and their hospital laptop. The fixed x-ray detector system also had limitations when compared to conventional fixed x-ray systems. It was noted that the operator needs to manually input the exposure technical factor—something that is usually automatically calculated by conventional fixed x-ray systems.

Participants who operated a fixed and mobile x-ray machine commented that the connectivity issues involved with using the single-exposure, DES flat panel x-ray detector added time to work processes and delaying workflow. Repeat x-rays were required in cases where the DES image quality was poor.

Radiation

Radiologist stated the radiation dose may be slightly higher with the single-exposure, DES flat panel x-ray detector compared to conventional x-ray machines. The advantage noted was the 3 images can be obtained from a single radiation exposure. Participants also noted that having to manually set the exposure factors may lead to under- or over-exposure since these factors are automatically calculated in a fixed x-ray machine. Using the single-exposure, DES flat panel x-ray detector for larger patients may require an additional x-ray to be taken, increasing the radiation exposure to the patient. However, the radiation dose of the DES detector is significantly lower than that of a CT scan.

System Level Context

Participants who did not have direct experience using the single-exposure, DES flat panel x-ray detector had varying perspectives on the value of the DES detector and were uncertain if this technology fills a care gap. Alternative approaches to the single-exposure, DES flat panel x-ray detector were mentioned, such as existing tools within image viewing software that allows for the enhancement of the x-ray images. Participants also mentioned the AI solutions currently available and the emerging advancements with AI technology. Low dose CT scans were also cited as an alternative currently used in the clinical setting for specific clinical indications.

Participants also considered matters related to workflow. They noted that a majority of intensivists are trained to interpret chest x-ray images at the bedside to confirm the placement of lines and tubes and to help with clinical decision making. These images are subsequently read and interpreted by a radiologist. Some participants hypothesized about whether the additional single-exposure, DES flat panel x-ray detector images may contribute to an increase in workload for radiologists as the number of x-ray images to review increases 3-fold.

Discussion

Outreach for this stakeholder perspectives summary yielded engagement with 20 health care providers who had expertise with x-ray systems. A key strength of this engagement was the inclusion of the perspectives of health care professionals who had direct experience with the single-exposure, DES flat panel x-ray detector in a clinical setting within Ontario. Participants with experience using the DES detector technology spoke about the barriers and facilitators to its usability. Those who had the opportunity to interpret the x-ray images produced by a DES detector in a clinical setting were supportive of this technology and perceived an increase in confidence with diagnosing patients. However, participants mentioned barriers with retrofitting. Those who operated an x-ray system (i.e., x-ray technologists) including the DES detector commented on issues related to workflow, including the physical specifications, connectivity, battery life, and maneuverability as barriers to use.

Participants who did not have experience using the single-exposure, DES flat panel x-ray detectors expressed their uncertainty regarding the benefits compared to the alternative options currently in use in Ontario, such as image enhancing software, emerging AI technology, and low dose CT scanning.

Limitations

There were a small number of participants who had experience using the single-exposure, DES flat panel x-ray detectors. All users with direct experience with the DES detector used it for only a short period of time and could not speak to the long-term applicability of this technology. None of the users had experience with a fully integrated mobile x-ray system (i.e., a mobile x-ray system that did not require retrofitting to be compatible with the single-exposure, DES detector). Such a system had not yet been granted Health Canada approval during the development of this HTA. Non-users applied their expertise in diagnostic imaging and currently available imaging techniques to consider the benefits of the single-exposure, DES flat panel x-ray detectors for clinical care. Although we engaged with a large number of stakeholders, not all perspectives were captured.

Conclusion

Users who viewed and interpreted the images produced by the single-exposure, DES flat panel x-ray detectors spoke positively about their experience with the technology and expressed an increase in confidence when making a diagnosis. Those responsible for operating the x-ray systems with the single-exposure, DES flat panel x-ray detectors mentioned operability issues as the main barrier to workflow. The experiences of providers with a fully integrated mobile x-ray system are unknown at this time. Participants noted the importance of user involvement when local hospitals assess their imaging needs and when considering usingo use single-exposure, DES flat panel x-ray detectors.

Conclusions of the Health Technology Assessment

The use of single-exposure, dual-energy subtraction (DES) flat panel x-ray detectors may lead to an improvement in the sensitivity and specificity to detect pulmonary nodule calcification compared with conventional x-ray, but the evidence for its effect on the visibility of the tips of lines and tubes, diagnostic confidence, and the time to review the x-ray images compared with conventional x-ray is very uncertain.

The lack of evidence on potential benefits to the diagnostic accuracy of chest x-rays using single-exposure, DES flat panel detectors and the potential impact on patient management have introduced large uncertainty into the value of this new technology. When contextualized within the use of chest x-rays in the Ontario institutional setting, our analysis estimated that purchasing 3 detectors to retrofit with available x-ray machines may lead to an additional cost of $12,137 per institution. However, given the large degree of uncertainty around the costs and implications of this technology, our analyses are limited in their ability to represent the budget impact from a provincial public payer perspective or in complex application scenarios for Ontario institutions.

Users who viewed and interpreted the images produced by single-exposure, DES flat panel x-ray detectors spoke positively about their experience with the technology and expressed an increase in confidence when making a diagnosis. Those responsible for operating the retrofitted x-ray systems with the DES detector mentioned operability issues as the main barrier to the workflow. Participants noted the importance of user involvement when local hospitals assess their imaging needs and when considering using single-exposure, DES flat panel x-ray detectors.

Abbreviations

AI: Artificial intelligence

CAD: Computer-aided detection

CT: Computed tomography

DES: Dual-energy subtraction

GRADE: Grading of Recommendations Assessment, Development, and Evaluation

HTA: Health technology assessment

ICU: Intensive care unit

NICE: National Institute for Health and Care Excellence

PICC: Peripherally inserted central catheter

QALY: Quality-adjusted life-year

Glossary

Budget impact analysis: A budget impact analysis estimates the financial impact of adopting a new health care intervention on the current budget (i.e., the affordability of the new intervention). It is based on predictions of how changes in the intervention mix will impact the level of health care spending for a specific population. Budget impact analyses are typically conducted for a short-term period (e.g., 5 years). The budget impact, sometimes referred to as the net budget impact, is the estimated cost difference between the current scenario (i.e., the anticipated amount of spending for a specific population without using the new intervention) and the new scenario (i.e., the anticipated amount of spending for a specific population following the introduction of the new intervention).

Discounting: Discounting is a method used in economic evaluations to adjust for the differential timing of the costs incurred and the benefits generated by a health care intervention over time. Discounting reflects the concept of positive time preference, whereby future costs and benefits are reduced to reflect their present value. The health technology assessments conducted by Ontario Health use an annual discount rate of 1.5% for both future costs and future benefits.

Equity: Unlike the notion of equality, equity is not about treating everyone the same way.[67] It denotes fairness and justice in process and in results. Equitable outcomes often require differential treatment and resource redistribution to achieve a level playing field among all individuals and communities. This requires recognizing and addressing barriers to opportunities for all to thrive in our society.

Fleiss' Kappa: A statistical technique to measure the inter-observer agreement between 2 or more reviewers of a categorical variable or variables. The observers independently review the same data. Their responses are then compared to determine the level of agreement.

Incremental cost: The incremental cost is the additional cost, typically per person, of a health care intervention versus a comparator.

Incremental cost-effectiveness ratio (ICER): The incremental cost-effectiveness ratio (ICER) is a summary measure that indicates, for a given health care intervention, how much more a health care consumer must pay to get an additional unit of benefit relative to an alternative intervention. It is obtained by dividing the incremental cost by the incremental effectiveness. Incremental cost-effectiveness ratios are typically presented as the cost per life-year gained or the cost per quality-adjusted life-year gained.

Ministry of Health perspective: The perspective adopted in economic evaluations determines the types of costs and health benefits to include. Ontario Health develops health technology assessment reports from the perspective of the Ontario Ministry of Health. This perspective includes all costs and health benefits attributable to the Ministry of Health, such as treatment costs (e.g., drugs, administration, monitoring, hospital stays) and costs associated with managing adverse events caused by treatments. This perspective does not include out-of-pocket costs incurred by patients related to obtaining care (e.g., transportation) or loss of productivity (e.g., absenteeism).

Probabilistic analysis: A probabilistic analysis (also known as a probabilistic sensitivity analysis) is used in economic models to explore uncertainty in several parameters simultaneously and is done using Monte

Carlo simulation. Model inputs are defined as a distribution of possible values. In each iteration, model inputs are obtained by randomly sampling from each distribution, and a single estimate of cost and effectiveness is generated. This process is repeated many times (e.g., 10,000 times) to estimate the number of times (i.e., the probability) that the health care intervention of interest is cost-effective.

Quality-adjusted life-year (QALY): The quality-adjusted life-year (QALY) is a generic health outcome measure commonly used in cost–utility analyses to reflect the quantity and quality of life-years lived. The life-years lived are adjusted for quality of life using individual or societal preferences (i.e., utility values) for being in a particular health state. One year of perfect health is represented by one quality-adjusted life-year.

Reference case: The reference case is a preferred set of methods and principles that provide the guidelines for economic evaluations. Its purpose is to standardize the approach of conducting and reporting economic evaluations, so that results can be compared across studies.

Scenario analysis: A scenario analysis is used to explore uncertainty in the results of an economic evaluation. It is done by observing the potential impact of different scenarios on the cost-effectiveness of a health care intervention. Scenario analyses include varying structural assumptions from the reference case.

Time horizon: In economic evaluations, the time horizon is the time frame over which costs and benefits are examined and calculated. The relevant time horizon is chosen based on the nature of the disease and health care intervention being assessed, as well as the purpose of the analysis. For instance, a lifetime horizon would be chosen to capture the long-term health and cost consequences over a patient's lifetime.

Uptake rate: In instances where two technologies are being compared, the uptake rate is the rate at which a new technology is adopted. When a new technology is adopted, it may be used in addition to an existing technology, or it may replace an existing technology.

Utility: A utility is a value that represents a person's preference for various health states. Typically, utility values are anchored at 0 (death) and 1 (perfect health). In some scoring systems, a negative utility value indicates a state of health valued as being worse than death. Utility values can be aggregated over time to derive quality-adjusted life-years, a common outcome measure in economic evaluations.

Appendices

Appendix 1: Literature Search Strategies

Clinical Evidence Search

Search Date: January 22, 2024

Databases Searched: Ovid MEDLINE, Embase, Cochrane Central Register of Controlled Trials, and NHS Economic Evaluation Database

Database segments: EBM Reviews - Cochrane Central Register of Controlled Trials <December 2023>, EBM Reviews - Cochrane Database of Systematic Reviews <2005 to January 17, 2024>, EBM Reviews - NHS Economic Evaluation Database <1st Quarter 2016>, Embase <1980 to 2024 Week 03>, Ovid MEDLINE(R) ALL <1946 to January 19, 2024>

Search Strategy:

----

1 X-Rays/ (111109)
2 exp Radiography, Thoracic/ (269343)
3 (radiogra* or roentgenogra* or x-ray* or xray* or x-radiation).ti,ab,kf. (1552479)
4 Point-of-Care Systems/ (21786)
5 Point-of-Care Testing/ (26749)
6 (bedside* or bed-side* or point-of-care* or poc or poct or portable* or mobil* or transportabl*).ti,ab,kf. (1223667)
7 or/1-6 (2940184)
8 Radiography, Dual-Energy Scanned Projection/ (185797)
9 (((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj3 (detect* or device* or flat-panel* or one-expos* or one-shot* or projection* or single-shot* or single-expos* or subtract*)) or DL-FPD* or DLFPD* or TL-FPD* or TLFPD*).ti,ab,kf. (2503)
10 ((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj (imag* or scan* or technolog*)).ti,ab,kf. (1149)
11 ((reveal* adj10 ("35C" or mobi pro*)) or spectraldr* or calneo*).ti,ab,kf. (12)
12 or/8-11 (188753)
13 7 and 12 (68822)
14 ((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj3 (detect* or device* or flat-panel* or one-expos* or one-shot* or projection* or single-shot* or single-expos* or subtract*) adj3 (xray* or x-ray*)).ti,ab,kf. (324)
15 or/13-14 (68822)
16 15 use medall,coch,cctr,cleed (856)
17 exp Animals/ not Humans/ (16436316)
18 16 not 17 (822)
19 limit 18 to english language [Limit not valid in CDSR; records were retained] (772)
20 X ray detector/ (1097)
21 exp thorax radiography/ (228182)

22 (radiogra* or roentgenogra* or x-ray* or xray* or x-radiation).tw,kw,kf,dv. (1559056)
23 "point of care system"/ (21250)
24 "point of care testing"/ (26749)
25 mobile x ray unit/ (893)
26 (bedside* or bed-side* or point-of-care* or poc or poct or portable* or mobil* or transportabl*).tw,kw,kf. (1228538)
27 or/20-26 (2903072)
28 dual layer flat panel detector/ (2)
29 (((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj3 (detect* or device* or flat-panel* or one-expos* or one-shot* or projection* or single-shot* or single-expos* or subtract*)) or DL-FPD* or DLFPD* or TL-FPD* or TLFPD*).tw,kw,kf,dv. (2559)
30 ((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj (imag* or scan* or technolog*)).tw,kw,kf,dv. (1555)
31 ((reveal* adj10 ("35C" or mobi pro*)) or spectraldr* or calneo*).tw,kw,kf,dv. (30)
32 or/28-31 (3744)
33 27 and 32 (1689)
34 ((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj3 (detect* or device* or flat-panel* or one-expos* or one-shot* or projection* or single-shot* or single-expos* or subtract*) adj3 (xray* or x-ray*)).tw,kw,kf,dv. (337)
35 or/33-34 (1689)
36 35 use emez (995)
37 (exp animal/ or nonhuman/) not exp human/ (12027941)
38 36 not 37 (919)
39 limit 38 to english language [Limit not valid in CDSR; records were retained] (793)
40 19 or 39 (1565)
41 40 use medall (755)
42 40 use emez (793)
43 40 use coch (0)
44 40 use cctr (17)
45 40 use cleed (0)
46 remove duplicates from 40 (1049)

Economic Evidence Search

Search date: January 22, 2024

Databases searched: Ovid MEDLINE, Embase, Cochrane Central Register of Controlled Trials, and NHS Economic Evaluation Database

Database: EBM Reviews - Cochrane Central Register of Controlled Trials <December 2023>, EBM Reviews - Cochrane Database of Systematic Reviews <2005 to January 17, 2024>, EBM Reviews - NHS Economic Evaluation Database <1st Quarter 2016>, Embase <1980 to 2024 Week 03>, Ovid MEDLINE(R) ALL <1946 to January 19, 2024>

Search Strategy:

----
1 X-Rays/ (111109)
2 exp Radiography, Thoracic/ (269343)
3 (radiogra* or roentgenogra* or x-ray* or xray* or x-radiation).ti,ab,kf. (1552479)
4 Point-of-Care Systems/ (21786)
5 Point-of-Care Testing/ (26749)
6 (bedside* or bed-side* or point-of-care* or poc or poct or portable* or mobil* or transportabl*).ti,ab,kf. (1223667)
7 or/1-6 (2940184)
8 Radiography, Dual-Energy Scanned Projection/ (185797)
9 (((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj3 (detect* or device* or flat-panel* or one-expos* or one-shot* or projection* or single-shot* or single-expos* or subtract*)) or DL-FPD* or DLFPD* or TL-FPD* or TLFPD*).ti,ab,kf. (2503)
10 ((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj (imag* or scan* or technolog*)).ti,ab,kf. (1149)
11 ((reveal* adj10 ("35C" or mobi pro*)) or spectraldr* or calneo*).ti,ab,kf. (12)
12 or/8-11 (188753)
13 7 and 12 (68822)
14 ((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj3 (detect* or device* or flat-panel* or one-expos* or one-shot* or projection* or single-shot* or single-expos* or subtract*) adj3 (xray* or x-ray*)).ti,ab,kf. (324)
15 or/13-14 (68822)
16 economics/ (265308)
17 economics, medical/ or economics, pharmaceutical/ or exp economics, hospital/ or economics, nursing/ or economics, dental/ (1080110)
18 economics.fs. (470496)
19 (econom* or price or prices or pricing or priced or discount* or expenditure* or budget* or pharmacoeconomic* or pharmaco-economic*).ti,ab,kf. (1325734)
20 exp "costs and cost analysis"/ (702097)
21 (cost or costs or costing or costly).ti. (341296)
22 cost effective*.ti,ab,kf. (469107)
23 (cost* adj2 (util* or efficacy* or benefit* or minimi* or analy* or saving* or estimate* or allocation or control or sharing or instrument* or technolog* or increment*)).ab,kf. (320503)
24 models, economic/ (16247)
25 markov chains/ or monte carlo method/ (110478)
26 (decision adj1 (tree* or analy* or model*)).ti,ab,kf. (70753)
27 (markov or markow or monte carlo).ti,ab,kf. (185176)
28 quality-adjusted life years/ (57625)
29 (QOLY or QOLYs or HRQOL or HRQOLs or QALY or QALYs or QALE or QALEs).ti,ab,kf. (116752)
30 ((adjusted adj1 (quality or life)) or (willing* adj2 pay) or sensitivity analys*s).ti,ab,kf. (204857)
31 or/16-30 (3484243)
32 15 and 31 (2394)
33 32 use medall,cctr (40)
34 15 use cleed,coch (0)
35 33 or 34 (40)
36 limit 35 to english language [Limit not valid in CDSR; records were retained] (39)
37 X ray detector/ (1097)

38 exp thorax radiography/ (228182)
39 (radiogra* or roentgenogra* or x-ray* or xray* or x-radiation).tw,kw,kf,dv. (1559056)
40 "point of care system"/ (21250)
41 "point of care testing"/ (26749)
42 mobile x ray unit/ (893)
43 (bedside* or bed-side* or point-of-care* or poc or poct or portable* or mobil* or transportabl*).tw,kw,kf. (1228538)
44 or/37-43 (2903072)
45 dual layer flat panel detector/ (2)
46 (((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj3 (detect* or device* or flat-panel* or one-expos* or one-shot* or projection* or single-shot* or single-expos* or subtract*)) or DL-FPD* or DLFPD* or TL-FPD* or TLFPD*).tw,kw,kf,dv. (2559)
47 ((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj (imag* or scan* or technolog*)).tw,kw,kf,dv. (1555)
48 ((reveal* adj10 ("35C" or mobi pro*)) or spectraldr* or calneo*).tw,kw,kf,dv. (30)
49 or/45-48 (3744)
50 44 and 49 (1689)
51 ((dual-energ* or dualenerg* or multi-energ* or multienerg* or dual-layer* or two-layer* or third-layer* or three-layer* or triple-layer*) adj3 (detect* or device* or flat-panel* or one-expos* or one-shot* or projection* or single-shot* or single-expos* or subtract*) adj3 (xray* or x-ray*)).tw,kw,kf,dv. (337)
52 or/50-51 (1689)
53 Economics/ (265308)
54 Health Economics/ or Pharmacoeconomics/ or Drug Cost/ or Drug Formulary/ (151014)
55 Economic Aspect/ or exp Economic Evaluation/ (564985)
56 (econom* or price or prices or pricing or priced or discount* or expenditure* or budget* or pharmacoeconomic* or pharmaco-economic*).tw,kw,kf. (1346147)
57 exp "Cost"/ (702097)
58 (cost or costs or costing or costly).ti. (341296)
59 cost effective*.tw,kw,kf. (477977)
60 (cost* adj2 (util* or efficac* or benefit* or minimi* or analy* or saving* or estimate* or allocation or control or sharing or instrument* or technolog* or increment*)).ab,kw,kf. (330398)
61 Monte Carlo Method/ (85682)
62 (decision adj1 (tree* or analy* or model*)).tw,kw,kf. (74175)
63 (markov or markow or monte carlo).tw,kw,kf. (188648)
64 Quality-Adjusted Life Years/ (57625)
65 (QOLY or QOLYs or HRQOL or HRQOLs or QALY or QALYs or QALE or QALEs).tw,kw,kf. (120108)
66 ((adjusted adj1 (quality or life)) or (willing* adj2 pay) or sensitivity analys*s).tw,kw,kf. (225700)
67 or/53-66 (2995552)
68 52 and 67 (107)
69 68 use emez (65)
70 limit 69 to english language [Limit not valid in CDSR; records were retained] (62)
71 36 or 70 (101)
72 71 use medall (39)
73 71 use emez (62)
74 71 use coch (0)
75 71 use cctr (0)

76 71 use cleed (0)
77 remove duplicates from 71 (71)

Grey Literature Search

Search date: February 22-29, 2024
Websites searched:
Alberta Health Evidence Reviews, Alberta Health Services, BC Health Technology Assessments, Canadian Agency for Drugs and Technologies in Health (CADTH), Institut national d'excellence en santé et en services sociaux (INESSS), Institute of Health Economics (IHE), Ontario Health Technology Assessment Committee (OHTAC), McGill University Health Centre Health Technology Assessment Unit, Centre Hospitalier de l'Universite de Quebec-Universite Laval, Contextualized Health Research Synthesis Program of Newfoundland (CHRSP), Health Canada Medical Device Database, International HTA Database (INAHTA), Agency for Healthcare Research and Quality (AHRQ) Evidence-based Practice Centers, Centers for Medicare & Medicaid Services Technology Assessments, Veterans Affairs Health Services Research and Development, Institute for Clinical and Economic Review, Oregon Health Authority Health Evidence Review Commission, Washington State Health Care Authority Health Technology Reviews, National Institute for Health and Care Excellence (NICE), Healthcare Improvement Scotland, Health Technology Wales, Ireland Health Information and Quality Authority Health Technology Assessments, Australian Government Medical Services Advisory Committee, Australian Safety and Efficacy Register of New Interventional Procedures -Surgical (ASERNIP-S), Monash Health Centre for Clinical Effectiveness, The Sax Institute (Australia), Pharmac (New Zealand), Italian National Agency for Regional Health Services, Belgian Health Care Knowledge Centre, Ludwig Boltzmann Institute for Health Technology Assessment, Swedish Agency for Health Technology Assessment and Assessment of Social Services, Norwegian Institute of Public Health-Health Technology Assessment, The Danish Health Technology Council (Behandlingsrådet)Ministry of Health Malaysia Health Technology Assessment Section, Sick Kids Paediatric Economic Database Evaluation (PEDE), Tuft's Cost-Effectiveness Analysis Registry, PROSPERO, EUnetHTA, ClinicalTrials.gov

Keywords used:
imaging, x-ray, detector, dual energy, multi-energy, multi-energies, subtraction, flat-panel, portable x-ray, mobile x-ray, point-of-care x-ray, reveal AND x-ray, reveal AND radiography, KA Imaging

Clinical results (included in PRISMA):	9
Economic results (included in PRISMA):	9
Ongoing HTAs (PROSPERO/EUnetHTA):	0
Ongoing clinical trials:	8

Appendix 2: Critical Appraisal of Clinical Evidence

Table A1: Risk of Bias[a] Among Diagnostic Accuracy Studies (QUADAS-C Tool)

Author, year	Risk of bias (QUADAS-2)				Applicability concerns (QUADAS-2)			Risk of Bias (QUADAS-C)			
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard	Patient selection	Index test	Reference standard	Flow and timing
Rogalla et al, 2024[42]	Unclear[b]	Low[c]	Not applicable[d]	Unclear[e]	Unclear[b]	Low[c]	Not applicable[d]	Unclear[b]	Low[c]	Not applicable[d]	Unclear[e]
Minato et al, 2023[21]	Low	Low[f]	Low	Low[g]	Low	Low	Low	Low	Low[f]	Low	Low[g]

Abbreviation: QUADAS, Quality Assessment of Diagnostic Accuracy Studies.

[a]Possible risk-of-bias levels: low, high, unclear.

[b]The authors stated that consecutive patients were included in the study, but information about eligibility criteria, number of patients screened, number considered eligible, and number excluded from the analysis was not provided in the publication; the characteristics of included patients were not provided. This affects our ability to determine the risk of bias for patient selection.

[c]The risk of bias for the conduction of the index test was considered low as it seems that the index test was conducted appropriately. However, the scale used to interpret the test results was not provided—we did not rate this criterion as posing a high risk of bias assuming that the scale was applied in a similar manner to both the review of the dual-energy subtraction x-ray images and the conventional x-ray image.

[d]No reference standard was used in the study.

[e]Information about the flow and timing of patient inclusion and exclusion was not provided in the study; i.e., number of patients screened, ineligible, and excluded from the analysis.

[f]The single-exposure, dual-energy subtraction x-ray image plus the conventional x-ray image were reviewed 4 weeks after the conventional x-ray image was reviewed. This wasn't considered as posing a risk of bias because conventional x-ray images are usually included when single-exposure, dual-energy subtraction x-ray images are reviewed.

[g]All patients received the same reference standard and all patients were included in the analyses. As per the eligibility criteria, the index test and the reference standard could have been conducted with a time lag of up to 3 months—the actual time lag between the two tests was not reported by the authors, so it is difficult to determine if this would have affected the risk of patient misclassification. We assumed that it would have affected the intervention and the comparator groups to the same extent and therefore we considered the risk of bias to be low.

Table A2: GRADE Evidence Profile for the Comparison of Single-Exposure, DES Soft Tissue, Bone, and Conventional X-Ray Images Versus Conventional X-Ray Images Alone

Number of studies (design)	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Upgrade considerations	Quality
Sensitivity for detecting pulmonary nodule calcification							
1 (observational)[21]	No serious limitations	Cannot be assessed	Serious limitations (−1)[a]	Serious limitations (−1)[b]	Undetected	Not applicable	⊕⊕ Low
Specificity for detecting pulmonary nodule calcification							
1 (observational)[21]	No serious limitations	Cannot be assessed	Serious limitations (−1)[a]	Serious limitations (−1)[b]	Undetected	Not applicable	⊕⊕ Low
Visibility of tips of lines and tubes							
1 (observational)[42]	Serious limitations (−1)[c]	Cannot be assessed	Very serious limitations (−2)[d]	Serious limitations (−1)[e]	Undetected	Not applicable	⊕ Very low
Confidence in diagnosis of pneumonia, pneumothorax, bone fractures, pulmonary nodules, and the visibility of the tip of lines/tubes							
1 (observational)[42]	Serious limitations (−1)[f]	Cannot be assessed	Very serious limitations (−2)[g]	Serious limitations (−1)[h]	Undetected	Not applicable	⊕ Very low
X-ray image reading time							
1 (observational)[42]	Serious limitations (−1)[i]	Cannot be assessed	Serious limitations (−1)[j]	Serious limitations (−1)[k]	Undetected	Not applicable	⊕ Very low

Abbreviations: DES, dual-energy subtraction; GRADE, Grading of Recommendations Assessment, Development, and Evaluation; RCT, randomized controlled trial.

[a]Comparator indirectness: conventional radiography is a commonly used imaging test and is an adequate comparator; however, the study did not include other commercially available x-ray systems and technologies that aim to enhance the quality of the x-ray image as comparators. Outcome indirectness: surrogate outcome—impact of testing on clinical outcomes was not assessed.

[b]Lack of statistical power to detect a difference between the intervention and the comparator for most analyses. The width of the confidence intervals could not be assessed as the information was not provided.

[c]Patient selection was considered unclear due to lack of information on eligibility criteria, characteristics of the patients included, and the number of patients screened and excluded.

[d]Population indirectness: unclear as information on eligibility criteria and patient characteristics was not provided. Testing indirectness: threshold (scale used) was not provided—unclear if it would differ from what is used in clinical practice. Comparator indirectness: conventional radiography is a commonly used imaging test and is an adequate comparator; however, the study did not include other commercially available x-ray systems and technologies that aim to enhance the quality of the x-ray image as comparators. Outcome indirectness: surrogate outcome was used—impact of testing on clinical outcomes was not assessed.

[e]Only the summary estimate was provided; i.e., results for each reviewer who participated in the study were not provided. Additionally, although the difference between groups was statistically significant based on the *P* value, the width of the confidence interval could not be assessed as the information was not provided.

[f]Patient selection was considered unclear due to lack of information on eligibility criteria, characteristics of the patients included, and the number of patients screened and excluded. A breakdown of the patient conditions under evaluation for this outcome was not provided. No reference standard was used: although the use of a reference standard (computed tomography scanning) in this context may not have been possible as the study population was comprised of patients hospitalized in the ICU, the lack of a reference standard does not permit an assessment of the validity of the study results.

[g]Population indirectness: unclear as information on eligibility criteria, patient characteristics, and patient conditions under evaluation for this outcome was not provided. Testing indirectness: threshold (scale used) was not provided—unclear if it would differ from what is used in clinical practice. Comparator indirectness: conventional radiography is a commonly used imaging test and is an

adequate comparator; however, the study did not include other commercially available x-ray systems and technologies that aim to enhance the quality of the x-ray image as comparators. Outcome indirectness: a surrogate outcome was used—the impact of testing on clinical outcomes was not assessed.

[h]Imprecision cannot be determined, as neither confidence intervals nor *P* values were provided. Additionally, only the summary estimate was provided; i.e., results for each reviewer who participated in the study were not provided.

[i]Patient selection was considered unclear due to lack of information on eligibility criteria, characteristics of the patients included, or the number of patients screened and excluded.

[j]Population indirectness: information on eligibility criteria, patient characteristics, and patient conditions evaluated was not provided. Comparator indirectness: conventional radiography is a commonly used imaging test and is an adequate comparator; however, the study did not include other commercially available x-ray systems and technologies that aim to enhance the quality of the x-ray image as comparators.

[k]Lack of statistical power to detect a difference between the intervention and the comparator. Only the summary estimate was provided; i.e., results for each reviewer who participated in the study were not provided. The width of the confidence intervals could not be assessed as the information was not provided.

Appendix 3: Selected Excluded Studies – Clinical Evidence

For transparency, we provide a list of studies that readers might have expected to see but that did not meet the inclusion criteria, along with the primary reason for exclusion.

Citation	Primary reason for exclusion
Li F, Engelmann R, Pesce LL, Doi K, Metz CE, Macmahon H. Small lung cancers: improved detection by use of bone suppression imaging--comparison with dual-energy subtraction chest radiography. Radiology. 2011 Dec;261(3):937-49.	Intervention (single-exposure, DES radiography using computed radiography; e.g., using phosphorous plates)
Mogami H, Onoike Y, Miyano H, Arakawa K, Inoue H, Sakae K, et al. Lung cancer screening by single-shot dual-energy subtraction using flat-panel detector. Jpn J Radiol. 2021 Dec;39(12):1168–73.	Population (lung cancer screening)
Szucs-Farkas Z, Schick A, Cullmann JL, Ebner L, Megyeri B, Vock P, et al. Comparison of dual-energy subtraction and electronic bone suppression combined with computer-aided detection on chest radiographs: effect on human observers' performance in nodule detection. AJR Am J Roentgenol. 2013 May;200(5):1006–13.	Intervention (single-exposure, DES radiography using computed radiography; e.g., using phosphorous plates)
Szucs-Farkas Z, Patak MA, Yuksel-Hatz S, Ruder T, Vock P. Single-exposure dual-energy subtraction chest radiography: detection of pulmonary nodules and masses in clinical practice. Eur Radiol. 2008 Jan;18(1):24–31.	Intervention (single-exposure, DES radiography using computed radiography; e.g., using phosphorous plates)
World Health Organization. WHO compendium of innovative health technologies for low-resource settings 2021. COVID-19 and other health priorities. Licence CC BY-NC-SA 3.0 IGO. Available from: https://www.who.int/publications/i/item/9789240032507	Type of study (no published studies included in the review)

Abbreviations: DES, dual-energy subtraction; WHO, World Health Organization.

Appendix 4: Characteristics of the Clinical Studies Identified

Table A3: Characteristics of the Clinical Studies Identified

Study, N, country, funding sources	Study design and characteristics	Population	Intervention	Comparator	Image review	Outcomes
Rogalla et al, 2024[42] N = 28 Canada Funding sources not provided[a]	Prospective Chest radiographs from 28 consecutive patients hospitalized in the ICU were reviewed Annotations were removed and cases were anonymized before images were reviewed	Consecutive patients hospitalized in the ICU	Single-exposure x-ray system Tube voltage: 120 kV FPD: single-exposure, DES FPD (SpectralDR, KA Imaging, Waterloo, Ontario, Canada) Conventional, DES bone and soft tissue x-ray images reviewed	Conventional x-ray image from the same x-ray system No reference standard used	Conventional x-ray images reviewed first Single-exposure, DES x-ray images reviewed 1 wk later X-ray images reviewed by 9 medical professionals with different experience levels (medical students, residents, fellows, chest radiologists) Images were processed to remove annotations and to anonymize the patient identification	Likelihood of pneumonia, pneumothorax, bone fractures, pulmonary nodules, and the visibility of the tip of lines/tubes (5-point scale[b]) Presence of motion artefacts Change in diagnostic confidence Time taken for image review
Minato et al, 2023[21] N = 139 patients (155 nodules [48 calcified/107 non-calcified]) Japan No funding provided for the study	Retrospective Hospital x-ray database searched for patients with chest radiographs with the word "nodule" 1 radiologist (5 y experience) assessed the eligibility criteria, which were confirmed by 2nd radiologist (18 y experience)—neither radiologist participated in the study The same 2 radiologists evaluated the CT images for nodule characteristics (location, pattern of calcification, type of non-calcified nodules, diameter, and	Patients with a chest radiograph (Jan 2019–Mar 2020) with the word "nodule" Performed using single-exposure, DES FPD CT scan within 3 mo of single-exposure, DES chest radiography Nodules ≤ 3 cm <u>Exclusion</u> Patients with > 3 nodules Unclear nodules on radiography	Single-exposure x-ray system Standing PA, in deep inspiration Tube voltage: 120 kV FPD: single-exposure, DES FPD (FUJIFILM DR CALNEO Dual, Fujifilm) Conventional and DES soft tissue x-ray images reviewed	Conventional x-ray image from the same x-ray system Reference standard for pulmonary nodule calcification: CT scan	Image reviewed using workstation with high-definition liquid crystal display monitor X-ray images reviewed by 5 radiologists (3–26 y experience) without referring to clinical characteristics or CT image	Sensitivity, specificity of pulmonary nodule calcification: 1–5[c] (levels 3–5 considered noncalcified) Change in inter-observer agreement (Fleiss' kappa[d])

Study, N, country, funding sources	Study design and characteristics	Population	Intervention	Comparator	Image review	Outcomes
	percentage of solid component in part-solid nodules) and overlap with bone					

Abbreviations: CT, computed tomography; DES, dual-energy subtraction; FPD, flat panel detector; ICU, intensive care unit; PA, posteroanterior.

[a]The authors received no financial support for the research, authorship, and/or publication of this article.

[b]5-point scale not provided.

[c]Calcified pulmonary nodule: containing diffuse or partial calcification; noncalcified nodule: nodules with no calcification at all. Levels of confidence: 1 = definitely calcified; 2 = probably calcified; 3 = equivocal; 4 = probably not calcified; 5 = definitely not calcified.

[d]Kappa interpretation: < 0.00, poor agreement; 0.00–0.20, slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; 0.81– 1.00, almost perfect agreement.

Appendix 5: Pulmonary Nodules Characteristics

Table A4: Pulmonary Nodules Characteristics

Study, N, country	Pulmonary nodule calcification,[a] n	Pulmonary nodule location,[a] n	Pattern of calcification,[a] n	Type of noncalcified nodule,[a] n	Pulmonary nodule diameter,[a] n
Minato et al, 2023[21] N = 155 nodules Japan	Calcified: 48 (31.0%) Noncalcified: 107 (69.0%)	Calcified nodules (N = 48) Right lung: 16 (33.3%) Left lung: 14 (29.2%) Right thoracic wall or skin: 9 (18.8%) Left thoracic wall or skin: 9 (18.8%) Noncalcified nodules (N = 107) Right lung: 59 (55.1%) Left lung: 43 (40.2%) Right thoracic wall or skin: 1 (0.9%) Left thoracic wall or skin: 4 (3.7%)	Diffuse: 41 (85.4%) Central: 5 (10.4%) Laminated: 1 (2.1%) Popcorn: 0 (0%) Other: 1 (2.1%)	Solid: 87 (81.3%) Partly solid: 20 (18.7%) Pure GGN: 0 (0%) % solid in partly solid nodules: < 50%: 2/20 (10.0%) ≥50%: 18/20 (90.0%)	Calcified nodules (N = 48) < 10 mm: 29 (60.4%) ≥ 10 mm: 19 (39.6%) Noncalcified nodules (N = 107) < 10 mm: 35 (32.7%) ≥ 10 mm: 72 (67.3%)

Abbreviation: GGN, ground glass nodule.
[a]Information based on the assessment of the computed tomography images by 2 radiologists, who didn't participate in the study.

Appendix 6: Clinical Study Results

Table A5: True Positive and True Negative Results According to Pulmonary Nodule Diameter

	Overall (N = 155)			Nodule diameter < 10 mm (n = 64)			Nodule diameter ≥ 10 mm (n = 91)		
Reviewer (experience)[a]	**Conventional x-ray image**	**Single-exposure, DES soft tissue plus conventional x-ray images**	***P***	**Conventional x-ray image**	**Single-exposure, DES soft tissue plus conventional x-ray images**	***P***	**Conventional x-ray image**	**Single-exposure, DES soft tissue plus conventional x-ray images**	***P***
Reviewer 1 (26 y)	139 (89.7%)	143 (92.3%)	.21	57 (89.1%)	58 (90.6%)	.66	82 (90.1%)	85 (93.4%)	.18
Reviewer 2 (14 y)	129 (83.2%)	136 (87.7%)	.18	51 (79.7%)	52 (81.3%)	.80	78 (85.7%)	84 (92.3%)	.08
Reviewer 3 (8 y)	123 (79.4%)	143 (92.3%)	< .001	50 (78.1%)	56 (87.5%)	.06	73 (80.2%)	87 (95.6%)	< .001
Reviewer 4 (6 y)	120 (77.4%)	135 (87.1%)	.007	44 (68.8%)	52 (81.3%)	.06	76 (83.5%)	83 (91.2%)	.05
Reviewer 5 (3 y)	98 (63.2%)	129 (83.2%)	< .001	40 (62.5%)	49 (76.6%)	.03	58 (63.7%)	80 (87.9%)	< .001

Abbreviation: DES, dual-energy subtraction.

[a]The reviewers were numbered 1 through 5 according to the study publication.[21]

Source: Minato et al[21]

Appendix 7: Selected Excluded Studies – Economic Evidence

For transparency, we provide a list of studies that readers might have expected to see but that did not meet the inclusion criteria, along with the primary reason for exclusion.

Citation	Primary reason for exclusion
Divino V, Schranz J, Early M, Shah H, Jiang M, DeKoven M. The annual economic burden among patients hospitalized for community-acquired pneumonia (CAP): a retrospective US cohort study. Curr Med Res Opin. 2020;36(1):151–60.	Not about adoption of x-ray technology
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(57):642–52.	Not about adoption of x-ray technology

Appendix 8: Results of Applicability Checklists for Studies Included in the Economic Literature Review

Table A6: Assessment of the Applicability of Studies Evaluating the Cost-Effectiveness of Single-Exposure, DES Flat Panel X-Ray Detectors

Author, year, country	Is the study population appropriate for the review question?	Are the interventions appropriate for the review question?	Is the system in which the study was conducted sufficiently like the current Ontario context?	Is the perspective of the costs appropriate for the review question (e.g., Canadian public payer)?	Is the perspective of the outcomes appropriate for the review question?	Are all future costs and outcomes discounted appropriately (as per current CADTH guidelines)?	Are QALYs derived using CADTH's preferred methods, or is an appropriate social care–related equivalent used as an outcome? (If not, describe rationale and outcomes used in line with the analytical perspective taken)	Overall judgment[a]
Karim et al, 2021[50]	Partially	Partially	Partially (a typical clinical site in the United States with a daily x-ray scan volume of ≤ 120)	Partially (likely from the healthcare system)	No (only costing comparison)	No discounting (1 y)	No (no QALY)	Not applicable

Abbreviations: CADTH, Canadian Agency for Drugs and Technologies in Health; QALY, quality-adjusted life-year.

Note: response options for all items were "yes," "partially," "no," "unclear," and "NA" (not applicable).

[a]Overall judgment may be "directly applicable," "partially applicable," or "not applicable."

Appendix 9: Interview Guide

Provider Perspectives Interview Guide

X-ray Technologist

1. What was the time period of use for the Reveal detector?
2. In what care setting was the Reveal detector used (ER, ICU, etc.)?
3. What was your experience with retrofitting the mobile x-ray machine in order to use the Reveal detector?
4. What was your experience with using the Reveal detector day to day? (consider the below points)
    - Heaviness of detector
    - Placement of laptop
    - User interface
    - Connectivity (Wi-Fi)
    - Battery life
    - Durability
    - Workflow
5. What were the challenges with using the Reveal detector?
6. What worked well when using the reveal detector?
7. Is there anything else you feel would be important for us to consider?
8. Training required
9. Ease of use

Radiologist

1. What was the time period of use for the Reveal detector?
2. In what care setting was the Reveal detector used (ER, ICU, etc.)?
3. What was your experience with retrofitting the mobile x-ray machine in order to use the Reveal detector?
4. What was your experience with using the Reveal detector? (consider the below points)
    - Diagnostic accuracy
    - Image Quality
    - Value of additional images
    - Avoidance of CT scan
    - Radiation exposure
5. What were the challenges with using the Reveal detector?
6. What worked well when using the reveal detector ?
7. Is there anything else you feel would be important for us to consider?
8. Training required
9. Ease of use

References

(1) National Institutes of Health (National Institute of Biomedical Imaging and Bioengineering). X-rays [Internet]. c2023 [cited 2023 Nov 27]. Available from: https://www.nibib.nih.gov/science-education/science-topics/x-rays

(2) Gilkeson RC, Sachs PB. Dual energy subtraction digital radiography: technical considerations, clinical applications, and imaging pitfalls. J Thorac Imaging.21(4):303-13.

(3) Kashani H, Gang JG, Shkumat NA, Varon CA, Yorkston J, Van Metter R, et al. Development of a high-performance dual-energy chest imaging system: initial investigation of diagnostic performance. Acad Radiol. 2009;16(4):464-76.

(4) CADTH Rapid Response Reports. Portable versus fixed x-ray equipment: a review of the clinical effectiveness, cost-effectiveness, and guidelines. Ottawa (ON): Canadian Agency for Drugs and Technologies in Health; 2016.

(5) Eisenhuber E, Schaefer-Prokop CM, Prosch H, Schima W. Bedside chest radiography. Respir Care. 2012;57(3):427-43.

(6) Oda S, Awai K, Funama Y, Utsunomiya D, Yanaga Y, Kawanaka K, et al. Detection of small pulmonary nodules on chest radiographs: efficacy of dual-energy subtraction technique using flat-panel detector chest radiography. Clin Radiol.65(8):609-15.

(7) Ahn JS, Ebrahimian S, McDermott S, Lee S, Naccarato L, Di Capua JF, et al. Association of artificial intelligence-aided chest radiograph interpretation with reader performance and efficiency. JAMA Netw Open. 2022;5(8):e2229289.

(8) Martini K, Baessler M, Baumueller S, Frauenfelder T. Diagnostic accuracy and added value of dual-energy subtraction radiography compared to standard conventional radiography using computed tomography as standard of reference. PLoS One. 2017;12(3):e0174285.

(9) Ontario Association of Radiologists. X-Ray [Internet]. c2023 [cited 2023 November 27]. Available from: https://oarinfo.ca/patient-info/radiology-medical-services/x-ray

(10) Urbaneja A, Dodin G, Hossu G, Bakour O, Kechidi R, Gondim Teixeira P, et al. Added value of bone subtraction in dual-energy digital radiography in the detection of pneumothorax: impact of reader expertise and medical specialty. Acad Radiol. 2018;25(1):82-7.

(11) Ley-Zaporozhan J, Shoushtari H, Menezes R, Zelovitzky L, Odedra D, Jimenez-Juan L, et al. Enhanced pneumothorax visualization in ICU patients using portable chest radiography. PLoS One. 2018;13(12):e0209770.

(12) Boswell GE, Wolfgramm ST, Fong RK, Hawley DB. Dual-energy, dual-exposure PA and lateral chest radiograph: not your father's chest x-ray. Mil Med. 2023;188(1-2):12-5.

(13) Manji F, Wang J, Norman G, Wang Z, Koff D. Comparison of dual energy subtraction chest radiography and traditional chest x-rays in the detection of pulmonary nodules. Quant Imag Med Surg. 2016;6(1):1-5.

(14) Gupta A, Kikano EG, Bera K, Baruah D, Saboo SS, Lennartz S, et al. Dual energy imaging in cardiothoracic pathologies: a primer for radiologists and clinicians. Eur J Radiol Open.8:100324.

(15) Ansari-Gilani K, Tandon YK, Jordan DW, Ciancibello L, Wilson DL, Gilkeson RC. Dual-energy subtraction chest radiography: application in cardiovascular imaging. J Thorac Imaging. 2020;35(3):W75-W81.

(16) van der Heyden B. The potential application of dual-energy subtraction radiography for COVID-19 pneumonia imaging. Br J Radiol. 2021;94(1120):20201384.

(17) Cai EY, De Caro C, Treb K, Li K. Benefits of using removable filters in dual-layer flat panel detectors. Phys Med Biol. 2023;68(8):07.

(18) KA Imaging. SpectralDR Technology [Internet]. c2024 [cited 2024 Apr 19]. Available from: https://www.kaimaging.com/science-center/reveal-technology/
(19) Karim KS, Tilley Ii S. Portable single-exposure dual-energy x-ray detector for improved point-of-care diagnostic imaging. Mil Med. 2023;188(Suppl 6):84-91.
(20) MedImaging. Fujifilm showcases new DR detectors and AI initiative in Chicago [Internet]. 2018 [cited 2023 Nov 27]. Available from: https://www.medimaging.net/rsna-2018/articles/294775842/fujifilm-showcases-new-dr-detectors-and-ai-initiative-in-chicago.html
(21) Minato K, Yamazaki M, Yagi T, Hirata T, Tominaga M, You K, et al. Effectiveness of one-shot dual-energy subtraction chest radiography with flat-panel detector in distinguishing between calcified and non-calcified nodules. Scientific Reports.13(1):9548.
(22) Shah A, Iyengar KP, Botchu R. Gray scale inversion imaging (GSI) in trauma and orthopaedics. J Orthop. 2022;30:62-5.
(23) Ledda RE, Silva M, McMichael N, Sartorio C, Branchi C, Milanese G, et al. The diagnostic value of grey-scale inversion technique in chest radiography. Radiol Med. 2022;127(3):294-304.
(24) Gutiérrez-Ibarluzea I, Benguria-Arrate G, Galnares-Cordero L. Efectividad, seguridad e indicaciones de la tecnología radiológica de supresión de hueso para la detección de cáncer de pulmón: informes de evaluación de tecnologías sanitaria [Internet]. Comunidad Autónoma del País Vasco: Ministerio de Sanidad, Servicios Sociales e Igualdad; 2018 [cited 2023 Nov 23]. Available from: https://redets.sanidad.gob.es/documentos/Supresion_de_Hueso_Osteba.pdf
(25) Ontario Health Cancer Care Ontario. Lung cancer [Internet]. c2024 [cited 2023 Nov 27]. Available from: https://www.cancercareontario.ca/en/types-of-cancer/lung
(26) Ontario Health Cancer Care Ontario. Guidelines and advice: lung cancer screening information for healthcare providers [Internet]. c2024 [cited 2023 Nov 17]. Available from: https://www.cancercareontario.ca/en/guidelines-advice/cancer-continuum/screening/lung-cancer-screening-information/faqs-healthcare-providers
(27) Ost D, Fein AM, Feinsilver SH. Clinical practice. The solitary pulmonary nodule. N Engl J Med. 2003;348(25):2535-42.
(28) Canadian Association of Radiologists. Referral guidelines (Section F, Thoracic) [Internet]. 2012 [cited 2024 Feb 15]. Available from: https://car.ca/wp-content/uploads/Thoracic.pdf
(29) Del Giudice ME, Young S, Vella E, Ash M, Bansal P, Robinson A, et al. Referral of suspected lung cancer by family physicians and other primary care providers [Internet]. Toronto (ON): Cancer Care Ontario; 2019 [cited 2023 Nov 27]. Available from: https://www.cancercareontario.ca/en/guidelines-advice/types-of-cancer/216
(30) Mayo Clinic. Pneumothorax: overview [Internet]. c2024 [cited 2023 Nov 22]. Available from: https://www.mayoclinic.org/diseases-conditions/pneumothorax/symptoms-causes/syc-20350367
(31) Ganapathy A, Adhikari NK, Spiegelman J, Scales DC. Routine chest x-rays in intensive care units: a systematic review and meta-analysis. Crit Care. 2012;16(2):R68.
(32) Health Canada Medical Device Active Licence Listings. Reveal 35C Flat Panel Detector (Licence 105205) [Internet]. c2024 [cited 2024 May 9]. Available from: https://health-products.canada.ca/mdall-limh/information?deviceId=1025093&licenceId=105205&identifier=REVEAL+35C&type=active&lang=eng
(33) KA Imaging. Reveal Mobi Pro [Internet]. [cited 2024 Apr 19]. Available from: https://kaimaging.com/medical-solutions/reveal-mobi-pro/
(34) Health Canada Medical Device Active Licence Listings. Reveal Mobi Pro (Licence 111209) [Internet]. [cited 2024 May 14]. Available from: https://health-products.canada.ca/mdall-

limh/information?deviceId=1065140&deviceName=REVEAL%20MOBI%20PRO&licenceId=111209&type=active&lang=eng
(35) O'Neill J, Tabish H, Welch V, Petticrew M, Pottie K, Clarke M, et al. Applying an equity lens to interventions: using PROGRESS ensures consideration of socially stratifying factors to illuminate inequities in health. J Clin Epidemiol. 2014;67(1):56-64.
(36) McGowan J, Sampson M, Salzwedel DM, Cogo E, Foerster V, Lefebvre C. PRESS peer review of electronic search strategies: 2015 guideline statement. J Clin Epidemiol. 2016;75:40-6.
(37) Covidence systematic review software. Veritas Health Innovation. Melbourne (Australia) [Internet]. [cited 2023 Nov 17]. Available from: https://www.covidence.org/home
(38) Yang B, Mallett S, Takwoingi Y, Davenport CF, Hyde CJ, Whiting PF, et al. QUADAS-C: a tool for assessing risk of bias in comparative diagnostic accuracy studies. Ann Intern Med. 2021;174(11):1592-9.
(39) Schünemann H, Brożek J, Guyatt G, Oxman A, editors. GRADE handbook [Internet]. Hamilton (ON): Grade Working Group; 2013 [Internet] [cited 2023 Nov 16]. Available from: https://gdt.gradepro.org/app/handbook/handbook.html
(40) World Health Organization. WHO compendium of innovative health technologies for low-resource settings 2021. COVID-19 and other health priorities. Licence CC BY-NC-SA 3.0 IGO. [Internet]. [cited 2024 Apr 19]. Available from: https://www.who.int/publications/i/item/9789240032507
(41) Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Syst Rev. 2021;10(1):89.
(42) Rogalla P, May M, Ronghe S, Kandel S, Potipcoe J, Patil NS, et al. Improved visibility of lines and tubes on portable dual-energy chest x-ray: assessment in a non-radiological reviewing environment. Can Assoc Radiol J. 2024:8465371241238953.
(43) National Institutes of Health. Feasibility of multi-energy digital radiography detector for lung lesions detection (NCT03528733) [Internet]. [cited 2024 Apr 24]. Available from: https://clinicaltrials.gov/study/NCT03528733
(44) Chou PC, Karim KS. Single-exposure dual-energy radiography for the subtraction of in-dwelling devices in the soft tissue image. Presented at the European Congress of Radiology, 2023 (Poster number C-15921) [Internet]: Eur Soc Radiol; 2023 [cited 2024 Apr 23]. Available from: https://epos.myesr.org/poster/esr/ecr2023/C-15921
(45) Maurino SL, Karim KS, Venkatesh V, Tilley S. Diagnostic value of single-exposure dual-energy subtraction radiography in lung lesion detection: initial results. Presented at the European Congress of Radiology, 2022 (Poster number C-15595) [Internet]: European Society of Radiology; 2022 [cited 2024 Apr 23]. Available from: https://epos.myesr.org/poster/esr/ecr2022/C-15595
(46) Tijmes FS, Kandel S, May M, Ronghe S, Rogalla P. Diagnostic value of dual-energy chest x-ray in immunocompromised patients to rule out pneumonia: initial results. Presented at the European Congress of Radiology, 2021 (Abstract number RPS 504-3) [Internet]: European Society of Radiology; 2021 [cited 2024 Apr 23]. Available from: https://insightsimaging.springeropen.com/counter/pdf/10.1186/s13244-021-01014-5.pdf
(47) Covidence systematic review software. Veritas Health Innovation. Melbourne (Australia). Available at: https://www.covidence.org/home.
(48) National Institute for Health and Care Excellence. Developing NICE guidelines: the manual (PMG20). London: The Institute; 2014 [updated 2024 Jan 17; cited 2024 Feb 20]. Appendix H: Appraisal checklists, evidence tables, GRADE and economic profiles. Available from: https://www.nice.org.uk/process/pmg20/resources/appendix-h-appraisal-checklists-evidence-tables-grade-and-economic-profiles-pdf-8779777885

(49) Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Journal of Clinical Epidemiology [Internet]. 2021 [cited 2021 May 27]; 134: 178-89. Available from: https://www.sciencedirect.com/science/article/pii/S0895435621000731
(50) Karim KS. Single-exposure, digital, dual-energy subtraction x-ray ushers in a new era of diagnostic x-ray imaging. Radiol Manag. 2021;43(2):23-30.
(51) Minato K, Yamazaki M, Yagi T, Hirata T, Tominaga M, You K, et al. Effectiveness of one-shot dual-energy subtraction chest radiography with flat-panel detector in distinguishing between calcified and non-calcified nodules. Sci Rep. 2023;13(1):9548.
(52) Ministry of Health. Schedule of facility costs for integrated community health services centre under the Integrated Community Health Services Centres Act. Toronto (ON): King's Printer for Ontario; 2023. p. 47.
(53) Ministry of Health. Schedule of benefits: physician services under the health insurance act [Internet]. Toronto (ON): King's Printer for Ontario; 2023 [cited 2023 Jun 29]. Available from: https://www.ontario.ca/files/2024-01/moh-ohip-schedule-of-benefits-2024-01-24.pdf
(54) Lifecycle guidance for medical imaging equipment in Canada [Internet]. Ottawa (ON): The Canadian Association of Radiologists; 2013 [cited 2024 Jan 25]. Available from: https://car.ca/wp-content/uploads/car-lifecycleguidance-mainreport.pdf
(55) Grand River Hospital to transform x-ray technology with KA Imaging's RevealTM 35C [Internet]. Grand River Hospital; 2022 [cited 2024 Jan 22]. Available from: https://www.grhosp.on.ca/news/2022/grand-river-hospital-to-transform-x-ray-technology-with-ka-imagings-revealtm-35c
(56) Block Imaging. Digital x-ray detector panel price guide [Internet]. Holt (MI): Block Imaging; c2024 [cited 2024 Jan 25]. Available from: https://www.blockimaging.com/dr-panel-price-cost-guide
(57) Block Imaging. How to convert to digital x-ray: steps to convert analog x-ray to digital x-ray for crisp digital images [Internet]. Holt (MI): Block Imaging; c2016 [cited 2024 Jan 25]. Available from: https://www.blockimaging.com/hubfs/Non-searchables/how-to-convert-to-digital-x-ray.pdf
(58) National Institute for Health and Care Excellence. Early value assessment interim statement: NICE process and methods [PMG39]. London (UK): The Institute; 2022.
(59) Liljegren E. Usability in a medical technology context assessment of methods for usability evaluation of medical equipment. Int J Ind Ergon. 2006;36(4):345-52.
(60) Kuzel AJ. Sampling in qualitative inquiry. In: Miller WL, Crabtree BF, editors. Doing qualitative research. Thousand Oaks (CA): Sage; 1999. p. 33–45.
(61) Morse J. Emerging from the data: cognitive processes of analysis in qualitative research. In: Morse J, editor. Critical issues in qualitative research methods. Thousand Oaks (CA): Sage; 1994. p. 23-41.
(62) Patton MQ. Qualitative research and evaluation methods. 3rd ed. Thousand Oaks (CA): Sage; 2002.
(63) Strauss AL, Corbin JM. Basics of qualitative research: techniques and procedures of developing a grounded theory. 2nd ed. Thousand Oaks (CA): Sage; 1998.
(64) Strauss AL, Corbin JM. Grounded theory research: procedures, canons, and evaluative criteria. Qual Sociol. 1990;13(1):3-21.
(65) Strauss AL, Corbin JM. Grounded theory methodology: an overview. In: Denzin NK, Lincoln YS, editors. Handbook of qualitative research. Thousand Oaks (CA): Sage; 1994. p. 273-85.
(66) NVivo qualitative data analysis software. QSR International (Doncaster, Victoria, Australia). Available at: https://www.qsrinternational.com/nvivo/home.

(67) Ontario Health's equity, inclusion, diversity and anti-racism framework [Internet]. Toronto (ON): Ontario Health; 2022 [cited 2023 Mar 22]. Available from: https://www.ontariohealth.ca/sites/ontariohealth/files/2020-12/Equity%20Framework.pdf

About Us

We are an agency created by the Government of Ontario to connect, coordinate, and modernize our province's health care system. We work with partners, providers, and patients to make the health system more efficient so everyone in Ontario has an opportunity for better health and well-being.

Equity, Inclusion, Diversity and Anti-Racism

Ontario Health is committed to advancing equity, inclusion and diversity and addressing racism in the health care system. As part of this work, Ontario Health has developed an Equity, Inclusion, Diversity and Anti-Racism Framework, which builds on existing legislated commitments and relationships and recognizes the need for an intersectional approach.

Unlike the notion of equality, equity is not about sameness of treatment. It denotes fairness and justice in process and in results. Equitable outcomes often require differential treatment and resource redistribution to achieve a level playing field among all individuals and communities. This requires recognizing and addressing barriers to opportunities for all to thrive in our society.

For more information about Ontario Health, visit OntarioHealth.ca.

About the Ontario Health Technology Advisory Committee

How to Obtain Reports From the Ontario Health Technology Assessment Series

Disclaimer

Ontario Health
500–525 University Avenue
Toronto, Ontario
M5G 2L3
Toll Free: 1-877-280-8538
TTY: 1-800-855-0511
Email: OH-HQO_HTA@OntarioHealth.ca
hqontario.ca

ISSN 1915-7398 (online)
ISBN 978-1-4868-8548-0 (PDF)

Need this information in an accessible format? 1-877-280-8538, TTY 1-800-855-0511, info@OntarioHealth.ca

Document disponible en français en contactant info@OntarioHealth.ca