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Digital Mammography versus Film-Screen Mammography: Technical, Clinical and Economic Assessments

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Digital Mammography versus Film-Screen Mammography: Technical, Clinical and Economic Assessments

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As lead author, Dr. Chuong Ho led the project protocol development, supervised the literature review, was in charge of the Clinical Effectiveness Review section, revised the report, and prepared the report for publication. Dr. David Hailey was in charge of the Technology Review section, worked with Dr. Ho to retrieve articles, evaluate their relevance, assess their quality and to extract data. Dr. Rebecca Warburton was in charge of the Economic Analysis section and constructed and analysed the economic model. Dr. John MacGregor and Dr. Etta Pisano provided clinical expertise and contributed to the draft document and its subsequent revisions. Ms. Janet Joyce was responsible for the design and execution of the literature seach strategies; for writing the section and associated appendix on literature searching; and for verifying and formatting the bibliographic references.

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No conflicts of interests were declared by any of the authors.

Dr. John Lewin has served as a consultant to GE Medical Systems and Eastman Kodak Company in the past, but is not currently serving as such. He has no financial stake in those companies or any other digital mammography company. He currently serves as a consultant to MiraMedica, Inc., a start-up company developing a mammography CAD system. He has minimal financial interest in that company. His institution has research agreements with GE Medical systems and is negotiating an agreement with Fischer Imaging. These involve performing research in exchange for free use of equipment. He receives no financial benefit from these agreements.

REPORT *IN BRIEF*

October 2002

Digital Mammography versus Film-Screen Mammography: Technical, Clinical and Economic Assessments

Technology Name

Digital mammography systems for breast cancer detection.

Technology Description

Mammography is an X-ray examination of the breast used to detect breast cancer. The current standard, film-screen mammography (FSM), has several inherent limitations on image quality. Digital mammography (DM) was developed as a convenient alternative that is expected to improve the quality of breast imaging and reduce the radiation dose required. DM involves the digital capture of images through two different technologies:

- Digital radiography mammography (DR-M) is a direct system; X-ray information is directly converted into a digital image. Total annualized capital and operating costs for a single DR-M may be as much as $249,000 more than FSM.
- Computed radiography mammography (CR-M) is an indirect system; X-ray information is captured on a detector plate, from which a digital image is created. Total annualized capital and operating costs for CR-M are equivalent to FSM.

Disease/Condition

Breast cancer is the most common cancer to affect women. It is the second leading cause of cancer death in Canadian women after lung cancer. Each year in Canada as estimated 19,500 women are diagnosed with breast cancer and 5,500 die from it.

The Issue

Is DM more expensive than FSM? Is DM more clinically effective than FSM?

Assessment Objectives

To compare the technical, clinical and potential costs of DM and FSM within the context of the Canadian health care system based on a systematic review of published and unpublished studies.

Methodology

An electronic search with no language restrictions was conducted of published and conference literature. The results were screened using different filters for the technology review, the clinical review and the economic analysis. Irrelevant reports were excluded based on title and abstracts. Full reports were then evaluated and relevant reports were accepted for final inclusion. Thus, the technical review was based on 37 relevant articles; the clinical review on 7; and the economic analysis on 17.

Conclusions

DR-M has significantly higher annualized costs than either FSM or CR-M. Potential clinical benefits (improved diagnostic accuracy, shorter examination time, lower radiation dose) for patients, institutions and payers have not been demonstrated in a clinical setting. The ability to detect cancer is comparable for DR-M and FSM. (There is not sufficient data on clinical effectiveness of CR-M). Assuming that DR-M and CR-M are, at best, clinically equivalent to FSM, the minimum-cost system is preferred; therefore, conventional FSM is preferable to DM at this time.

This summary is based on a comprehensive health technology assessment report available from CCOHTA's web site (www.ccohta.ca): Ho C, Hailey D, Warburton R, MacGregor J, Pisano E, Joyce J. **Digital mammography versus film-screen mammography: technical, clinical and economic assessments**.

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EXECUTIVE SUMMARY

The Issue

Breast cancer is the second leading cause of cancer death in Canadian women after lung cancer and is the most common cancer to affect women. Screening mammography is based on the concept that early detection of breast cancer increases the chance of reducing death and morbidity from the disease. Breast self-examination, clinical breast examination and mammography are three screening techniques for breast cancer. Film screen mammography (FSM) is the standard approach used in mammographic breast cancer screening, but an alternative approach, digital mammography (DM), has been developed in an effort to overcome some of the disadvantages of FSM.

Objectives

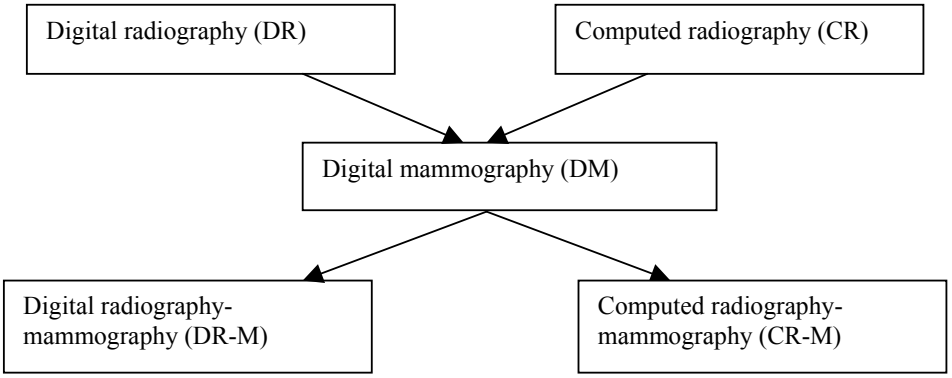
1) To perform a systematic review of published studies to describe and compare the technological aspects of DM and FSM
2) To perform a systematic review of published and unpublished studies to assess and compare the clinical effectiveness of DM and FSM
3) To synthesize the available evidence and model the potential costs and effects of DM and FSM within the context of the Canadian health care system

Technology Review

Studies were obtained after systematic searching of multiple electronic databases. Relevant studies were independently selected by two reviewers. These studies were used to describe and compare the technical aspects of DM and FSM.

DM involves digital capture of images through two different technologies: digital radiography (DR) and computed radiography (CR). In DR, X-ray photons interact with a detector and the detector directly converts the X-ray information into an electrical signal. This is processed to yield a digital image that can be viewed on a monitor (soft copy) or sent to a laser printer to generate a film image (hard copy). In CR, X-ray photons interact with a detector plate, a latent image is captured and the plate is taken to a reader where it is scanned by a laser. The scanning process generates an electrical signal that is processed into a digital image. As with DR, the digital image can be viewed as soft copy or sent to a printer to yield a film that is viewed in the conventional manner. Currently, manufacturers of DR systems have tended to employ electronic reporting and archiving, while CR systems employ film.

DM consists of two systems (see diagram below): Digital Radiography Mammography (DR-M) and Computed Radiography Mammography (CR-M). In this report, the use of DR to produce a digital image that is viewed on a monitor and archived electronically is referred to as Digital Radiography-Mammography (DR-M). Computed Radiography-Mammography (CR-M) refers to the use of CR to produce a hard copy film from a laser printer for image interpretation and storage.



Potential advantages of DM over FSM are, elimination of artefact and noise related to film processing, wider dynamic range, greater contrast resolution, ability to process images to better depict abnormalities, lower radiation dose, shorter examination times, suitability for computer-aided diagnosis (CAD), digital archiving, removal of procedural burden with X-ray films, and teleradiology applications. Potential disadvantages of DM over FSM are lower spatial resolution and generation of large amounts of information challenging for transmitting and archiving. A number of studies comparing reader performance in DM and FSM using receiver operating characteristic analysis have found similar results for the two approaches.

At the time of writing, six commercial DM systems have been developed by Fischer Imaging, Fuji Medical Systems, General Electric Medical Systems, Hologic and Sectra. These DM systems are based on different detection principles.

Clinical Effectiveness Review

Relevant studies from published and unpublished sources were identified using the same process as for the technology review. Due to the limited number of published clinical trials and their heterogeneity, no attempt was made to pool the data quantitatively. Rather, a qualitative summary of the literature was undertaken.
Limited evidence indicated that DM might result in fewer women being recalled for additional workup after a screening examination. DM was not found to be superior or inferior to FSM for screening, based on receiver operating curve analysis and cancer detection rate. There was a large variability in interpretation of images. Studies also showed that DM is better for visualizing subcutaneous structures, while FSM is limited in detecting microcalcifications in dense breast tissue. Although CR would be expected to have performance similar to DR, there was limited direct evidence of similarities or differences.

Economic Review and Analysis

Our economic analysis synthesized available evidence to model the likely costs and effects for society as a whole for FSM, DR-M, and CR-M in 2002 Canadian dollars. Modeled costs included equipment purchase and maintenance, non-radiologist staff wages and benefits, film-related supplies and repeat exams. Sensitivity analysis compared the base case (expected costs) to three alternate scenarios (minimum costs maximum costs and 3% discount rate). The analysis

reported is an *ex ante* (before-the-fact) cost-minimization analysis, which assumes that FSM, DR-M and CR-M are clinically equivalent.

This analysis assumes that DR-M images will be interpreted in soft copy (on a work station) and that no hard copy will be produced or stored except for patient transfers and film copy requests. A further assumption is that CR-M images will be interpreted by hard copy (film) and that film will be the method of image storage. This assumption on CR-M is based on the status of the only clinically available CR-M system to-date (Fuji Medical Systems).

Total annualized capital and operating costs for a DR-M system are expected to be 38% (C$137,000) higher than FSM, with a minimum estimated difference of 4% (C$14,000) and a maximum of 58% (C$249,000). CR-M has approximately equivalent costs to FSM. DR-M has higher equipment purchase costs ($1.1 million versus $180,000 for FSM or CR-M). The operating cost saving from shorter DR-M examination times, reduced film usage, and reduced repeat examinations are not sufficient to offset these higher capital costs.

Conclusions

Despite some technological advantages (improved diagnostic accuracy, lower radiation dose), potential clinical benefits of DM for patients, institutions and payers have not yet been demonstrated. DM offers advantages through the ability to manipulate images and to transmit them; it also makes telemammography a realistic possibility. The available literature comparing the clinical effectiveness of DR-M to FSM failed to show the superiority of DR-M. DR-M has significantly higher annualized costs than either FSM or CR-M systems. If DR-M and CR-M are, at best, clinically equivalent to FSM, the minimum-cost system would be preferred; therefore, conventional FSM is preferable to DM at this time.

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ABBREVIATIONS

CAD:	computer-aided diagnosis or computer-assisted diagnosis
CR:	computed radiography
CR-M:	computed radiography mammography (digital image acquisition, film for reporting/archiving)
DM:	digital mammography, digital image acquisition (DR or CR technologies)
DR:	digital radiography
DR-M:	digital radiography mammography (digital image acquisition, workstation for reporting, electronic archiving)
FSM:	conventional film-screen mammography
FFDM:	full-field digital mammography (synonym for DR-M)

1 INTRODUCTION

Background

Breast cancer is the second leading cause of death due to cancer in Canadian women after lung cancer, and is the most common cancer to affect women. Each year in Canada an estimated 19,500 women are diagnosed with breast cancer and 5,500 women die from this malignancy. Breast self-examination, professional palpation and mammography are three screening techniques for breast cancer.

Mammography has been shown to significantly contribute to breast cancer detection, but has limitations. Film-screen mammography (FSM), in which X-ray images of the breast are captured on film, currently dominates the market and offers good capability of detection of early breast tumours at a relatively low cost. However, despite recent improvements in traditional FSM, current detection methods still miss some breast cancers.

Digital mammography (DM) is a relatively new technology where X-ray film is replaced by solid-state detectors that convert X-rays into electric signals. The electric signals are used to produce images of the breast that can be seen on a computer screen or printed on special film. This allows the ability to “zoom” and enhance images, which can be stored and transmitted electronically. This technology is expected to improve the quality of breast imaging, particularly of radiodense tissue, at a reduced radiation dose as compared to conventional, film-based mammography. It can also reduce the number of repeat examinations and allows image manipulation to aid diagnosis.

Despite the promise of advantages through the use of DM for screening, it is not clear that the new technology is better than conventional FSM for the early detection of breast cancer. Film mammography remains the standard for breast cancer screening.

2 OBJECTIVES

To examine DM and to compare it to conventional FSM, three objectives were addressed.

1) Perform a systematic review of published studies to describe and compare the technological aspects of DM and FSM.
2) Perform a systematic review of published and unpublished studies to assess and compare the clinical effectiveness of DM and FSM.
3) Synthesize the available evidence and model the potential costs and effects of DM and FSM within the context of the Canadian health care system.

More specifically, this review addresses the following questions:

a) What are the technical characteristics of DM and how do they differ from those of FSM?
b) What are the established or potential advantages and disadvantages of DM?
c) How does computer-aided diagnosis (CAD), a technology that can be used in association with FSM or DM, fit?
d) What are the sensitivity and specificity of the interpretations of DM and FSM for screening and for diagnosis?
e) What are the economic implications (costs and effects) of DM within context of the Canadian health care system from a ministry of health perspective and for society as a whole?
f) How do the costs of DM and FSM compare?

3 TECHNOLOGY REVIEW

3.1 Methods

3.1.1 Literature search strategy

Published and conference literature, with no language restrictions, was identified by searching electronic databases on the OVID Technologies Inc. system, on July 31, 2001. The search was performed on MEDLINE®, CANCERLIT®, HealthSTAR®, EMBASE®, Biological Abstracts/RRM®, and INSPEC® (Appendix 1). Records were imported to the Reference Manager® database, and duplicates were eliminated. The Cochrane Library Issue 2, 2001 was searched on CD-ROM. The National Library of Medicine's PubMed was searched on October 14, 2001. An update Dialog® OneSearch®, from which duplicates were eliminated, was performed on April 8, 2002 on MEDLINE®, CANCERLIT®, EMBASE®, Biosis Previews®, and INSPEC® (Appendix 1).

Many web sites, including those of the International Network of Agencies for Health Technology Assessment (INAHTA) were searched to identify planned, ongoing and completed projects and reports. The websites of near-HTA agencies and specialized databases, such as the University of York National Health Service (NHS) Centre for Reviews and Dissemination (CRD), were searched, as were trial registries, (for example, the MetaRegister of Controlled Trials). Websites such as Health Canada Therapeutic Products Directorate *Medical Device Product Licences Issued*, and manufacturers' websites were searched.

Extensive Internet searching using the Google™ search engine was performed to obtain grey literature, such as conference abstracts and papers.

3.1.2 Selection criteria

Inclusion:

- The study be relevant to the objectives of the project, as stated above.
- The technology examined must involve system(s) where X-ray film is replaced by detectors that convert X-rays into electrical signals, which are then used to produce images of the breast in a computer system.

Exclusion: Publication as a letter, editorial, short note, or a second publication of the same study presenting the same results means the material will be excluded.

3.1.3 Selection strategy

Selection of potentially relevant studies: two reviewers (CH and DH) reviewed citations and discarded irrelevant ones, based on the title of the publication and the information available in the abstract.

Selection of relevant studies: photocopies of papers describing the potentially relevant studies were retrieved and two reviewers (CH and DH) independently made a final selection of the relevant studies based on the inclusion criteria; any differences were resolved by discussion and consensus.

3.1.4 Data extraction

Due to the nature and scope of literature on mammography technology, no attempt was made to extract data systematically, or to quantitatively pool results. Rather, each report was reviewed and summarized qualitatively.

3.2 Results

3.2.1 Quantity of research available

The original electronic search strategy identified 479 reports; an updated electronic search identified an additional 81. The two searches therefore yielded 560 reports. Of these, 153 potentially met selection criteria and were retrieved as full articles for more detailed evaluation. Of the 153, 116 articles did not meet selection criteria and were excluded, leaving 37 relevant articles. (For flow of the documents, see Appendix 2.)

3.2.2 Description of the technologies under assessment

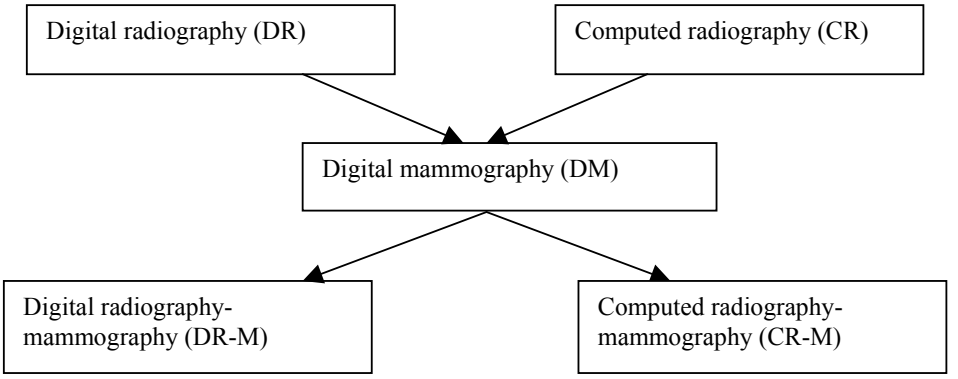
DM is a technology that is intended to replace FSM, which is currently the standard method used in diagnosis of and screening for breast neoplasms. Mammography is a demanding radiological technique due to the need for high image quality. This can be achieved with FSM only by paying meticulous attention to exposure and processing of the film.

DM involves digital capture of image through two different technologies: digital radiography (DR) and computed radiography (CR); DM refers to both types of digital image acquisition. In DR, X-ray photons interact with a detector and the detector directly converts the X-ray information into an electrical signal. This is processed to yield a digital image that can be viewed on a monitor (soft copy), stored digitally, or sent to a laser printer to generate a film image (hard copy). In CR, which is the most commonly used to date, X-ray photons interact with a detector plate, a latent image is captured and the plate is taken to a reader where it is scanned by a laser. The scanning process generates an electrical signal that is processed into a digital image. As with DR, the digital image can be viewed as soft copy, stored digitally, or sent to a printer to yield a film that is viewed in the conventional manner (see Figure 1 below). Currently, manufacturers of DR systems have tended to employ electronic reporting and archiving, while CR systems employ film.

DM consists of two unique types of system: Digital Radiography Mammography (DR-M) and Computed Radiography Mammography (CR-M). In this paper, the use of DR to produce a digital image that is viewed on a monitor and archived electronically will be referred to as Digital Radiography-Mammography (DR-M). Computed Radiography- Mammography (CR-M) will

refer to the use of CR to produce a hard copy film from a laser printer for image interpretation and storage (Figure 1).

Figure 1



3.2.3 Technical characteristics

FSM has several inherent limitations, as Feig & Yaffe point out[1]. These include a relatively high radiation dose, potential for loss of contrast, noise from the random fluctuation of X-ray absorption by the fluorescent screen and film emulsion, trade off between spatial resolution and detection efficiency of the film and screen, and inefficiency in rejecting scatter radiation.

In FSM, the X-ray film is used both to acquire and display the image. In DM, image acquisition and display operations are separated.[1,2] As with FSM, in DM the breast is compressed and exposed to a spectrum of X-rays, which are transmitted and scattered in the breast. However, after exposure of the breast to X-rays, the image formed by transmitted radiation is acquired by a detector which converts the X-ray signals to electronic signals. The electronic data are digitised into one of 2^n intensity levels. Typically n, the number of bits of digitisation, is 12 or 14, giving 4,096 or 16,384 image signal levels.

Processing of the digital signal is then performed by a computer. After processing, a digital mammogram can be displayed using either a hard copy or soft copy approach. In a hard copy display the image is printed onto a light-sensitive material, generally by scanning with a laser beam, and then viewed on a light box or multiviewer, in the same way as an FSM mammogram. Soft copy display is typically performed on a high-resolution video monitor. Digital data can also be stored electronically, on CD-ROM for example, in contrast to the need for hard copy storage of FSM mammograms.

The relationship between the transmitted X-ray intensity and the recorded digital signal is essentially linear; this is a key difference from FSM and contributes to the potential for digital image acquisition to reduce rates of repeat examinations. The display characteristics of the image, that is the image grey scale, can be altered for printing or viewing on a monitor.[1,2]

Availability of the image in digital form gives the potential for computer-aided diagnosis (CAD), with pattern recognition programs being used to provide additional information and opinion as

an aid to human readers of mammograms. Data available to date on the performance of CAD are limited to studies on its use with FSM.

X-ray tube parameters: Huda et al.[3] studied the effect of X- ray tube operating parameters on image quality in digital acquisition, using phantoms (objects, used for X-ray calibration, that mimic the radiation absorption characteristics of tissue). They found that reductions in potential (kVp) generated an increase in subject contrast, but there were no significant differences in imaging performance with changes in this parameter. They suggest that reduced subject contrast at higher potentials was offset by an increase in the image display contrast. Implications for clinical use are that if contrast is not reduced with higher potential settings, use of higher kVps would reduce patient doses and also exposure times, reducing discomfort associated with breast compression. Doubling the current (mA) value did not significantly affect detection performance, but there was a decrease when radiation dose was reduced by a factor of two.

Radiation dose: Because of the ability to adjust display contrast, it is generally found that more penetrating X-ray beams are used for DM. Even small increases in tube potential lead to a reduction in patient dose. The combination of increased detector quantum efficiency and reduced receptor noise allows for the possibility of dose reductions in digital acquisition as compared to FSM[1]. A phantom-based study by Obenauer et al.[4] also suggested the potential for dose reduction with digital acquisition.

Cowen et al.[5] state that attempts to reduce the digital acquisition dose per image compared with reference FSM system have proved fruitless and that this is not surprising given the similar detective quantum efficiencies of the two types of system. In clinical practice, however, there may be dose savings due to the linear dose response curve in digital acquisition, resulting in fewer repeat exposures. Cowen suggests that second-generation direct imaging systems must offer a patient dose reduction by a factor of two (or preferably greater) without compromising image quality. Alternatively, they should offer a significant improvement in image quality if current patient doses are retained. DR-M may not have the same limitations as CR-M in dose reduction.

Direct and indirect digital image acquisition: The most basic way of acquiring mammographic images as digital data is by digitisation of film images using a digitiser.[6] This can be done using laser film scanners or charge coupled devices sensors. Cowen comments that neither of these indirect approaches to acquiring digital images has achieved widespread clinical acceptance. Digitisation of film creates extra work for the radiographer, while providing little or no new information that is not available on the original mammogram. New noise introduced through the digitisation process may also cause image degradation.

The first digital image acquisition technology suitable for mammography was photo-stimulable phosphor radiography referred to in this paper as Computed Radiography. In this approach, X-ray photons interact with a phosphor screen known as an image plate which stores a latent image as a pattern of electrons trapped in the crystal structure. The electrons are released by scanning the plate with red laser light, which produces blue light emission. The blue light photons are collected using a light guide and detected by a photomultiplier tube. The resulting time series voltage signal is digitised. Digitised data can then be processed and images viewed as laser hardcopy or a workstation display.

Cowen[6] has provided a summary of benefits and problems with "first generation" DM (CR-M) using photo stimulable based phosphor technology (Table 1).

Table 1: Performances of first generation DM systems (CR-M)

Benefits	• Convenient, consistent, reliable acquisition of images • Images with superior contrast resolution and dynamic range compared with FSM • Superior quality images for women with dense breasts compared with FSM • Compatibility with digital image enhancement, transmission and archiving
Problems	• Occasional failure of the image plate read system • Dust and dirt accumulated on image plates can cause false positives in micro-calcification detection • Hardcopy format, size and layout • Sub-optimum computer enhancement of images • Inadequate spatial resolution • Little or no potential for reducing patient radiation dose compared with FSM • Higher equipment costs, as compared to FSM

Source: reference[6]

Like FSM, CR-M is an indirect method of acquiring X-ray images. Clinical images only become available for radiographic checking some minutes after X-ray exposure of the person being examined. Cowen comments that the full clinical benefits of DM will only be realised when the images are acquired directly in digital form using 'second generation' DR (also referred to as full-field DM).

There has been considerable research and development on DR-M systems. Yaffe and Rowlands,[7] in their review of detectors for DR, describe a number of approaches including scanned-beam acquisition (slot beam, time delay integration), image intensifier-based detectors, charge coupled devices, and flat panel systems for direct conversion of X-ray signals to electric charge based on amorphous selenium.

Haus and Yaffe[8] describe the four types of commercially produced systems available in late 1999. The MicroDose Digital Mammography system (Sectra Medical Systems, Sweden) and Hologic's Selenium detector system, which converts X-ray photons directly to digital data, are expected to be ready for clinical trials in 2002 [2] (Table 2).Yin et al.[9] have reported results obtained from prototype direct conversion detectors.

Table 2: Commercial DM systems

Name (type)	Manufacturer/ Developer	Detector	Principle
SenoScan (Scanned detector)	Fischer Imaging, Denver, CO	Fibreoptic coupling of CsI[Tl] phosphor to a CCD	Time delay integration. X-rays collimated into a fan beam, matching format of detector array; detector scans across the breast in synchrony with the beam.
Computed Radiography (Photostimulable phosphor)	Fuji Medical Systems, Stanford, CT	BaFCl[Eu] phosphor	After exposure, phosphor plate is removed and scanned with a laser to release light which is detected and digitised.
Senographe 2000D (Amorphous silicon)	General Electric Medical Systems, Milwaukee, WI	Photodiodes with layer of CsI[Tl] deposited on amorphous silicon plate	Matrix of photodiodes in the plate; charge produced on each diode in response to light emission from the phosphor is read out and digitised.
Trex Digital Mammography System (Large area mosaic)	Hologic, Bedford, MA	Fibreoptic coupling of CsI[Tl] phosphor to CCD detectors.	Mosaic of 3x4 detector elements, images from each are combined and digitised.
Microdose DM system	Sectra, Stockholm, Sweden	Silicon dioxide	Directly converts X-ray photon signals to digital data.
Lorad Full Field DM system	Hologic, Inc., Bedford, MA	Selenium	Directly converts X-ray photon signals to digital data.

BaFCl[Eu]: europium – doped barium fluorochloride
CsI[Tl]: thallium activated caesium iodide phosphor
CCD: charge coupled devices
Sources: References[2,8]

Kallergi et al.[10] have commented that the greatest challenge in detector development was the size and spatial resolution. All detection systems under development or available have lower spatial resolution than that of screen film but all claim improved contrast resolution, which is expected to compensate for the reduced spatial resolution. The detective quantum efficiency of newer detector systems in DR-M is higher than that of film-screen systems (40-60% compared to 25%) giving the potential for good image quality.[11]

Display and reading of images: Image processing is necessary in DM as the detector has a large dynamic range (1:10,000 for CR-M and at least 1:10,000 for other detectors) and this must be reduced to the range of a hardcopy film or a monitor (about 1:100).[11]

Haus and Yaffe[8] point out that with soft copy viewing, brightness of the display is far less than that of a conventional viewing box and the dynamic range is less than that of mammographic film. Ambient light in the viewing area must therefore be minimised. For hard copy display, maximum optical density of laser films is lower than for mammography film. This limitation of laser printed films challenges the assumption that CR-M images are equivalent to FSM. Cowen [6] states that evaluations of prototype designs of DM workstations have shown that softcopy

reporting can take up to 50% more time than film reporting (laser hard copy or standard mammographic film). However, performance in soft copy reporting is likely to have improved since then, with the introduction of newer technology.

Pisano et al.[12] discuss different display algorithms which have advantages and disadvantages for diagnosis and screening tasks in DM (Table 3). They conclude that different display image processing algorithms are likely to be useful for different tasks. Tailoring algorithms to optimise visualisation of different image features will not be easily achieved unless the current method of displaying mammograms is replaced by soft copy display.

Sivaramakrishna et al.[13] undertook a preference study in which four expert mammographers ranked unenhanced images and images enhanced using four types of algorithm. Algorithms improved the visibility of microcalcifications but there was no significant improvement observed for masses. These authors, like others, suggest the need for different imaging processing approaches, depending on the type of lesion.

Results from a study by Quiles et al.[14] suggested that digitised mammograms displayed on workstation monitors with a spatial resolution of 1280 x 1024 pixels were not inferior to conventional mammograms for the detection of microcalcifications.

Table 3: Image display algorithms for DM

Algorithm	Advantages	Disadvantages
Manual intensity windowing	Produces mammograms very similar to FSM mammograms	Limited by operator dependence
Histogram-based intensity windowing	Improves conspicuity of the lesion edge	Loss of detail outside the dense parts of the image
Mixture-model intensity windowing	Enhances visibility of lesion borders against the fatty background	Mixed parenchymal densities abutting the lesion may be lost
Contrast- limited adaptive histogram equalization	Can provide subtle edge information	Might degrade performance in the screening situation by enhancing visibility of nuisance information
Unsharp masking	Enhances the sharpness of the borders of mass lesions	May make even an indistinct mass appear more circumscribed
Peripheral equalization	Displays lesion details well, preserves peripheral information in the surrounding breast	May be flattening of image contrast in non-peripheral portions of the image
Trex processing	Allows visualisation of both lesion detail and breast edge information	Reduces image contrast

Source: Reference[12]

Shile et al.[15] presented early results from a study comparing time for radiologists to identify and assess changes in digital mammograms viewed on a work station compared to the time required for the same task on laser printed film using a multiviewer. The softcopy results were promising; three of four readers were slower with this method than with hardcopy but there were indications of a learning curve associated with soft copy reading and indications that viewing times for readers in later sessions were becoming shorter than for hard copy.

Kallergi et al.[10] raise questions to be addressed in relation to the workstation-user interface. These include: method of display for a digital mammogram, standards for image display, definition of optimum display, and description of new types of artifact. Also, quality control requirements for DM had not yet been fully defined (as of 1998).

Cowen[6] gives the following specification requirements for a DR-M softcopy reporting system:

- ultra-high resolution display monitors (2000 x 2,500 x 12 bits or greater); two or possibly four monitors required for a viable reporting station;
- a powerful CPU, large capacity /fast access hard disc and high speed RAM memory to support image processing, display and management;
- powerful fast default digital image enhancement (ensures optimum image quality is routinely produced);
- ability to manipulate images and print them in customized form to meet specific clinical needs;
- a powerful digital image database, effective image management software, high performance digital image archive;
- ability to access, recall and display images in a matter of seconds;
- support of laser printer control and computer networking; and
- ergonomically designed workstations that are intuitive and convenient for clinicians to use.

Data transfer and processing: Dhaenens[11] suggests that DM "becomes a victim of its own performance in terms of requirements for image processing. A mammographic image of 4000x4000x2 or higher carries between 30 and 50 Mbyte of data. This can make transmission slow and archiving expensive, requiring the best technology and excluding PC-based solutions."

Use of digital imaging techniques leads to generation of large amounts of information needed to store a digital image, especially if high quality is required. Various approaches have been developed to compress image files. Loss-less compression algorithms (i.e. preserving the information at 100%) have limited compression ratios and for general-purpose images, lossy techniques (i.e. allowing a little loss of information in a way that the quality of the image is not substantially altered) are considered more appropriate options.[16] Järvi et al.[17] describe development of a variable quality image compression system, using lossy compression but saving more details from important regions of the image than in other regions.

3.2.4 Computer-Aided Diagnosis (CAD)

The data obtained to date on the performance of CAD are limited to studies in which it has been used with FSM, however, it can be used with DM. Benefits of double reading of mammograms in terms of improving detection rates for breast cancer have been discussed by Kopans.[18] A hope is that availability of CAD systems will lead to more widespread use of this practice, which with human readers only is considered too expensive in some health systems. Kopans suggests, as DM systems become the norm and computer algorithms become more sophisticated, the second human reader will be replaced by a CAD system and double reading will become the norm.

Early approaches to automatic detection of calcifications in radiographically dense breasts have been discussed by Davies and Dance.[19] In 1997, Karssemeijer and Hendriks[20] concluded that performance of pattern recognition programs developed to help radiologists in detecting breast cancer was reaching a level where application seemed to be becoming worthwhile. However, they note that for densities and asymmetries the performance of CAD was still low and no results had been published that came close to the performance of human readers. Also, it was not yet known how radiologists in a real screening situation would deal with large numbers of false positives. They felt large trials were needed to demonstrate that computer assisted reading is beneficial. A 1999 paper by Schmidt[21] noted that detection programs for clustered calcifications had achieved reported sensitivities of over 90% with lower sensitivities for detection of masses and variable results for other signs of cancer. A commercially available clinical device became available in 1998.

Nishikawa et al.[22] have reported promising results with a system for automatic classification of clustered microcalcifications. In a comparison of 100 clinical images from 53 patients, the computer scheme correctly identified 82% of the 'benign patients' (all of whom had biopsies) and 100% of the malignant patients. In comparison, the average score from five radiologists for correctly classifying lesions as benign was only 27% at 100% sensitivity. Studies were under way to show that radiologists could use results of computer analyses to correctly classify breast lesions.

Hogge et al.[23] point out that a limitation in earlier investigations of CAD is that every research group is developing an algorithm based on its own clinical images and database and each differs in image quality and the number, subtlety and distribution of lesions encountered. Davies and Dance also noted the need for a database of high resolution, high quality mammograms containing all types of breast abnormality to permit comparisons between different techniques.

Similar points were made by Nishikawa and colleagues[24,25] who drew attention to the effect of case selection on performance of CAD schemes. In one study they found that sensitivity varied between 26% and 100% (at a false positive rate of one per image) depending on cases used to test the scheme. A 20% change in the cases comprising the database can reduce the measured sensitivity by 15 to 25 %. In their later study, variation in sensitivity of their CAD scheme varied from 77% to 100% with only 10% change in composition of the database. In addition, they noted the effects of different scoring protocols; measured sensitivity could be between 40 and 90% depending on the scoring methodology. Sharing databases, creating a common database or using a quantitative measure to characterize data bases are possible solutions to the problems, but were not in place in the early 1990s. Similar points have been made by Schiabel et al.[26,27] in more recent publications. Ashby et al.[28] have described development of a library of mammograms for evaluating the performance of calcification programs.

Work is continuing on approaches to CAD in DM. This includes a system for automatic detection of clustered microcalcifications[29] using a combination of methods. The first is based on difference-image techniques and the second a multi-resolution analysis of the image. Mendez et al.[30] and Bovis et al.[31] describe work on systems for the detection of masses. The approval by FDA in April 2002 of the use of CAD (R2's ImageChecker system by R2 Technology, Inc.) with the Senographe FFDM will provide data on the performance of CAD in DM.

3.2.5 Comparison of reader performance in DM and FSM

There have been a number of studies comparing reader performance in DM and FSM using receiver operating characteristic analysis. Among earlier studies, for example, Nab et al.[32] compared conventional mammograms viewed on a lightbox and digital mammograms with an image matrix of 2048 X 2048 on a high-resolution monitor. Two experienced radiologists read mammograms independently and rated their judgments about presence of cancers or microcalcifications on a confidence rating scale. The mammograms were selected from a Dutch archive. A set of 150 images was used for delectability of tumours and a second set of 120 mammograms was used for assessment of microcalcifications.

In this study, no statistically significant differences were found between judgments based on FSM and DM. The authors note that the radiologists were not familiar with use of interactive manipulation of contrast in DM. They also point out that the individual receiver operating characteristic curves are not applicable to the clinical situation in view of the high proportion of abnormal mammograms and absence of clinical information and data from other mammograms. However, the comparison between FSM and DM was considered valid. A study by Hildell et al.[33] based on use of phantoms indicated no difference in diagnostic performance of FSM and CR-M.

A more recent study by Gaspard-Bakhach et al.[34] also indicated similar findings for both FSM and phosphor storage DM using phantoms. Their clinical findings indicated a small advantage in favour of FSM, on the basis of receiver operating characteristic curves, but this was only weakly statistically significant. The receiver operating characteristic analysis reported by Lewin[35] as part of a clinical study also favoured FSM over full field DR-M, although the differences found were not statistically significant.

Huda et al.[3] draw attention to a comparison of DM and FSM using simulated masses imposed on an anthropomorphic breast phantom which showed superior performance for FSM; they suggest results obtained using simple contrast detail phantoms should be interpreted with great caution.

Cowen et al.[5] refer to a receiver operating characteristic study comparing CR-M with FSM in which the two modalities produced effectively identical micro-calcification detectability at receptor exposures equivalent to those producing optical density levels of 1.0 and 1.5 OD units with FSM. They point out that in mammography small detail detectability is dependent not only on spatial resolution but also on signal to noise considerations.

3.2.6 Future technologies

Niklason et al.[36] describe an approach to tomosynthesis breast imaging, based on obtaining images at discrete tube positions to avoid motion artifacts. Suggested advantages are: the development of an improved screening tool for women with radiographically dense breasts; and an advancement for problem solving and diagnosis with improvements in specificity and an ability to display the three-dimensional distribution of calcifications. A clinical trial of a General Electric tomosynthesis device is currently in progress.[2] Digital subtraction mammography, intended to detect differential blood flow to breast cancers compared to normal breast tissue, is also under development.

3.3 Discussion

Potential advantages and disadvantages of DM over FSM are listed in Tables 4 and 5, with commentary to provide additional perspective (drawn from several authors, including Bassett)[37].

Table 4: Potential advantages of DM, as compared to FSM

Potential Advantages of DM	**Comments**
Eliminates artifacts and noise related to film processing plus promises an ability to deliver a consistent image quality	Also artifacts with DM, though these may be less serious, e.g. Boyle [A] - motion artifact seen on slot-scanning DM, using a phantom; brief motion caused degradation of only a small part of the image; continuous motion produced smearing with DM and FSM -- they consider these results reassuring
Wider dynamic range	
Greater contrast resolution	
Able to process image to better depict abnormal or suspicious findings	
Potentially lower radiation dose for those being examined	Overall safety advantage over FSM (may not be significant)
Possibly shorter examination times, with reduced discomfort for those being examined	
Elimination of film library costs	Transfer and storage of digital mammograms is not cost-free
Elimination of lost films	Potential for loss, even with electronic archiving
More suitable for computer aided detection and diagnosis (CAD) programs	CAD programs still a developing area; their place in routine health care does not appear to be established as yet
Expected useful role in stereotactic biopsy procedures	
May be used in teleradiology	Staffing and other factors would need resolution before tele-mammography would be practical

Table 5: Potential disadvantages of DM, as compared to FSM

Potential Disadvantages of DM	**Comments**
Lower spatial resolution, fine detail of margins of masses and tiny calcifications may not be resolved	However, signal to noise considerations are also important in readability
For systems with only one size image receptor, large breasts cannot be completely shown without additional exposures to X-rays (DR-M)	
Capital costs are high	
High resolution workstations are needed to achieve the full benefits of DM and avoid the need to print out images for viewing; high resolution monitors (about 4000X 5000 pixels) are considered too expensive for general use.	
Workstations have to work fast if they are to be realistic for a screening service	
Generation of large amounts of information challenges transmitting and archiving	Systems capable of dealing with such levels of information are more available.
DM is not a single technology; its costs and capability will vary with the infrastructure that is available to individual operators	

4 CLINICAL EFFECTIVENESS REVIEW

4.1 Methods

The literature search strategy and selection criteria for this section are outlined in section 3.1. Outcome studies, in particular comparative trials reporting on DM and FSM, are included. A combined diagnostic/clinical study design filter was applied to the subject search (Appendix 1). Due to significant heterogeneity among the few clinical studies retrieved, no attempt was made to extract data systematically to allow quantitative pooling of results. Rather, each report was summarized and reviewed qualitatively.

4.2 Results

4.2.1 Quantity and quality of research available

The electronic search strategies identified 39 abstracts in total; these were all retrieved as full articles for more detailed evaluation. Of the 39, seven articles were selected for description within our report and the remaining 32 articles were determined to lack relevance.

4.2.2 Assessment of clinical effectiveness

Despite the advantages of DM with respect to contrast resolution and dynamic range, the transition from FSM to DM in practice has been slow; the clinical advantages of DM technology still require demonstration. In this report, our goal is to investigate the sensitivity and specificity of DM for the detection of breast cancer, as compared to FSM.

A study by Hendrick et al.[38] was funded by GE Medical Systems, Inc. for submission to the US Food and Drug Administration in support of pre-market approval of full-field digital mammography (FFDM, a synonym for DR-M). This study was designed to compare the performance of FFDM (GE medical Systems) to FSM. Both modalities were used to perform exams on 625 women aged 40 and over who presented for diagnostic mammography at four sites. Two views of each breast were acquired by each modality, using prototype GE FFDM systems, with breast doses equal to those in FSM. Images were interpreted independently by five Mammography Quality Standards Act (MQSA)-qualified radiologists. The results indicated that the recall rate for FFDM was lower than the recall rate for FSM by 2% ($p<0.001$) whether all cases or only non-cancer cases were considered (i.e. 46.9% vs. 48.8% and 45.4% vs. 47.3%, respectively). The specificity was 55% for FFDM and 53% for FSM. Sensitivity was 68% for FFDM and 70% for FSM ($p<0.02$). Using a null hypothesis that FFDM is inferior to FSM by more than a predetermined amount, this preliminary study showed FFDM is not inferior to FSM in terms of sensitivity, specificity, and recall rate.

A recent report summarized the work performed in a three-year study by Lewin[35] to evaluate FFDM as a screening tool for breast cancer. A clinical comparison of FFDM to FSM was completed with 6768 paired exams performed on 4521 women. The average age of all subjects

was 55.6 years. The Kodak Min R 2000 film-screen system was used to compare with the results of the predecessor to the Senographe 2000D (General Electric). The results indicated that 85% of the findings were discrepant between the two modalities. The causes of the differences between both modalities for the benign findings were mostly due to small random variations in the positioning of normal tissue and to minor differences of opinion among the readers. Among malignant findings (51 biopsy-diagnosed cancers) nine were detected with FFDM only, 16 with FSM only, 18 with both modalities, and eight were not detected with either modality. The reasons for discrepancy for the FFDM-only detected cancers were divided evenly into visibility/ conspicuousness, appearance, and interpretation. Reasons relating to interpretation were more common for FSM-only cancers (7/16) than for FFDM-only cancers (3/9), although not to a statistically significant degree. The discrepancy evaluation supports the importance of interpretation in diagnosing cancers, which included differences of opinion, errors, and workstation issues. In this study, the sensitivity for FFDM was 53% and for FSM was 67%. The difference was not statistically significant. Positive predictive value (PPV) of screening for FFDM was 3.4% and was the same for FSM. The recall rate for FFDM was statistically less than for FSM (11.9% and 15%, respectively). The area under the FSM curve was 0.6 higher than under the FFDM curve; the difference is not statistically significant. This study showed that the trends in both cancer detection and receiver operating characteristics analysis favoured FSM, though the results were not statistically significant.

In an earlier study by Hundertmark et al.,[39] 100 digital survey mammograms and 50 spot magnification views were performed and findings compared with those from FSMs on the same patients. The results showed the diagnostic value of digital mammograms using direct magnification technique is comparable to that of FSMs with regard to the identification of micro-calcifications. In 86% of the observations, it was possible to establish a concurrent evaluation of the detected microcalcifications. In 8% of the observations, microcalcifications were detected by DR-M that had not been recognized on previous FSM images. Spot magnification views allowed improvement in the detection of microcalcifications. When producing 4-fold spot magnifications, the digital magnification technique gave an additional 26% detection rate over the conventional analogue technique.

In an early pilot study by Jarlman et al.,[40] mammography using a CR approach (FRC-901, by Philips) was compared to FSM (Senograf 500 T unit, by GE), examining detectability of micro-calcifications and malignant tumours. Paired digital and conventional mammograms from 99 patients were reviewed, among them seven had biopsy-proven cancer, 30 had benign micro-calcifications and one had malignant microcalcification. The results showed that in the conventional mammograms true positive value was 31/31, while in the digital mammograms it was 29/31 (two benign micro-calcifications were missed by all three observers). The receiver operating characteristic curves regarding malignancy showed almost identical courses for both the digital and conventional mammograms.

In another study by Grebe et al.[41], more than 1000 digital mammograms (Senographe 2000D, GE Medical Systems) were compared with conventional mammograms (Senographe DMRplus, Philips UC Diagnost). The authors reported that DM provided a better visualization of the skin and subcutaneous structures. For the assessment of microcalcifications, the digital system in this study seemed superior to FSM: in very dense glandular tissue; in irradiated tissue after breast cancer surgery; and in dense breast of young patients. Through high-contrast resolution in the digital system and by appropriate windowing, the white-appearing calcifications can be

recognized. In contrast to this, FSM showed its limitations with respect to the detection of microcalcifications.

A study by Venta et al.[42] was performed to determine the rates and causes of disagreements in interpretation between DR-M (using a prototype Senographe 2000D), FSM (using Mammomat (Siemens), and DMR (the DMR is a conventional film screen mammography machine) units (GE) in a diagnostic setting. Radiologists independently assigned a Breast Imaging Reporting and Data System (BI-RADS) category to over 1100 paired mammograms, and grouped them into the general categories of agreement, partial agreement, or disagreement. Agreement between DR-M and FSM assessment was present in 82%, partial agreement in 14%, and disagreement in 4%, for a kappa value of 0.29. Screening mammograms had a higher rate of agreement than diagnostic mammograms (87% vs. 70%) and a lower rate of disagreement (2% vs. 7%) than diagnostic mammograms ($p<0.0001$). The primary causes of disagreement between DR-M and FSM interpretations of diagnostic mammograms were differences in management approach between radiologists (inter-observer variability) (52%), information from additional FSM images or ultrasound images of suspicious lesions (34%), and technical differences in the examinations (10%).

In a study by Hildell et al.,[33] storage phosphor (CR) was compared to FSM in terms of visibility and detectability of details of the breast parenchyma. A clinical series of 1200 women was examined with both techniques. Even though no detailed data were provided, it was reported that the appearance of irregular calcifications as well as smoothly rounded benign and "probably benign" calcifications was clearly appreciated with both modalities. The authors reported that evaluation of dense breasts was often easier on digital images, and the skin and the subcutaneous tissue could be evaluated without using high-intensity illumination.

4.3 Discussion

The available literature comparing the clinical effectiveness of DM to FSM failed to show the superiority of DM in the detection of breast cancer. Results indicate that sensitivity and specificity are very similar between the two modalities, although DM might have a lower recall rate.

In these studies, statistical power is limited by the small number of people with cancer in a population being screened. Large trials are necessary to increase statistical power. A large-scale trial is underway to determine whether DM is as sensitive, as specific, and as cost-effective as FSM in screening asymptomatic women. This Digital Mammographic Imaging Screening Trial (DMIST), led by principal investigator Etta Pisano from the University of North Carolina, Chapel Hill, will include 49,500 women at 19 centres in the US and Canada. The results are expected in late 2004. Another US trial led by Laurie Fajardo from the John Hopkins University School of Medicine, Baltimore, Maryland, is also in its second phase. This trial is a multi-centre clinical evaluation comparing optimized DM to FSM in over 1000 women with moderately or markedly dense breasts.

It is noteworthy, however, that even these larger studies may not have the power to answer all questions. If performance is comparable, the utilization of technology will depend on other

factors such as cost, and the success of fusion of digital images with expert systems software (CAD). The cost barrier must be judged in the context of increasing utilization of digital techniques in radiology departments and offices. The pressure for an office to be “all-digital” will grow and may make the high cost of DM less of an issue.

Due to the actual technological advantages and disadvantages of DM and FSM, each modality is expected to do well at detecting different types of cancer. The better contrast obtained with DM would facilitate the detection of masses and densities in dense breast. The achievable spatial resolution in DM is lower than in FSM, possibly limiting the detection of some types of lesions. However, the digital technique, in combination with the direct radiographic magnification technique, might overcome this limitation.

5 ECONOMIC ANALYSIS

5.1 Review of Economic Evaluations

5.1.1 Methods

The basic literature search strategy (Appendix 1) and selection criteria for this review are outlined in section 3.1. For this section, an "economic filter" was applied to the subject search to identify potentially relevant economic papers. The original electronic search strategy identified 73 abstracts, nine additional studies were identified by hand searching bibliographies and an updated electronic search identified another seven abstracts: total 89 articles. Of these, 17 were retrieved as full articles for more detailed evaluation; ultimately all were chosen for this report.

None of the selected sources reported rigorous evidence from randomized trials or systematic reviews. These sources also did not provide sufficient information on differences in examination times and differences in repeat examination rates.

Additional information was gathered using Internet searching (two papers, of which one is vendor-supplied). Available information (four papers) from the British Columbia (BC) digital imaging pilot project of the early 1990s was also included.

Limitations: High sensitivity and specificity rates for mammography would reduce costs for biopsy and other follow-up diagnostic and treatment services related to false-positive mammograms. Treatment effectiveness and survival rates also affect the cost-effectiveness of mammography programs. Such issues are not considered in this assessment, because diagnostic superiority has not been demonstrated for DM. Nor are emerging modalities (MRI, PET), and emerging diagnostic technologies (tomosynthesis, 3D imaging, synchrotron beam mammography, breast digital subtraction angiography, laser CT) considered in this review.

5.1.2 Results and discussion

Rigorous evidence about the costs and effects of FSM, DR-M, and CR-M is not available in the published literature. Many studies concerning DR-M and CR-M refer to costs but few provide actual cost information.

The following recent studies of DR-M (alphabetical by first author) provided sufficient cost information to assist with the *ex ante* modelling of costs in a subsequent section of this review. Evidence sources related to costs are summarized later in Table 6.

Cox and Schilling[43] reported DR-M system costs ranging from US$250,000 to US$500,000 in 1999. The lower-priced systems do not include image-reporting radiologist workstations.

Cupples and Anderson[44] reported 18-month costs and revenues (in 1996-1997) for a Siemens Mammomat 3000 unit including a digital spot biopsy add-on unit. Purchase price of approximately US$250,000 did not include a radiologist reporting workstation.

Dhaenens [11]discussed the technical and clinical requirements for DR-M and CR-M, and reported DR-M purchase prices of approximately US$500,000.

ECRI[45] summarized the evidence on DM, and noted that the cost of the GE Senographe 2000D (a DR-M unit including a 2-monitor reporting workstation) was approximately US$400,000-500,000 in March 2000. The review also noted reduced radiation dose compared to FSM and diagnostic accuracy comparable to FSM.

GE Medical Systems[46] reported the experience of the Institute for Breast Health in Oklahoma. In an eight-day period during July 2001, DR-M with the GE Senographe 2000D was found to reduce average diagnostic examination time by 43.4% (from 14.5 minutes to 8.2 minutes), to reduce average screening examination time by 29.5% (from 12.2 minutes to 8.6 minutes), to reduce repeat examinations by 1.48% of total examinations (from 1.76% to 0.28%), and to reduce film costs by US$128,000 per year (10,000 mammography examinations).

Hiatt et al.[47] reported costs for FSM and DM, based on FSM capital cost of US$40,000 to $60,000 and DM capital costs of US$90,000 to US$114,000. These capital costs are strikingly lower than those used by other authors. Capital costs were discounted at 2% (lower than the 3% to 5% commonly used in economic evaluation studies).

Johnson[48] reviewed the state of DR-M technology in the US and reported on expected capital and maintenance costs. The report states DR-M system costs are expected to be "$200,000 to $400,000—two to three times the cost of a good screen-film system". (This implies FSM costs of US$100,000 to US$133,000.) The report also states maintenance costs are expected to be higher for DR-M than for FSM systems and that the lower-cost DR-M systems do not include reporting workstations.

Nields and Galaty[49] reported diagnostic accuracy and costs for DR-M, citing increased capital costs (DR-M over FSM) of US $240,000. Based on prototype results indicating possible diagnostic superiority for DR-M over FSM, they reported that DR-M would reduce overall health care costs (compared with FSM) by reducing biopsies resulting from false positive mammography. (Until the diagnostic superiority of DR-M is actually demonstrated in routine clinical practice, this modelled finding is not relevant to policy.)

O'Riordan et al.[50] reported examination times and repeat examination rates for consecutive screening (not diagnostic) DR-M and FSM examinations (1000 each) at the University of Toronto. DR-M reduced average examination time by 42.1% (from 12.6 minutes to 7.3 minutes) and reduced repeat examinations by 3% of total (from 7.4% to 4.4%).

Roldan et al.[51] reported that digital imaging raised both radiation dose and costs (in 1992 Spanish pesetas) for mammography. Higher costs for DM were capital equipment (2.6 times FSM) and maintenance (2.2 times FSM; additional costs estimated at 5% of purchase price). Lower costs for DM were staff (-2.7%), materials (-7.2%), repeat examinations (reduced from 6.4% to 0.4%), and film archive costs (-24.3%).

Simonetti et al.[52] discussed technological developments in mammography, and noted that a CAD workstation (used for CAD on digital images scanned from conventional mammography films) was estimated to cost approximately US$100,000.

Warburton[53] reported results and projections from the BC digital imaging pilot project. The BC project excluded mammography, but compared costs and effects for a conventional department, a filmless medical imaging department with a picture archiving and communication system, and computed radiography. BC project data has been used to supplement published information on rates of film loss, workstation costs, picture archiving and communication system upgrade costs, maintenance costs, and staff costs.

The available literature indicates that DM (whether DR-M or CR-M) requires different capital equipment, has different operating costs and offers potential clinical benefits when compared with conventional FSM. This section describes the kinds of differences reported, and summarizes the expected differences between FSM, DR-M, and CR-M.

Capital equipment: As noted in previous sections of this review, the technical requirements for mammography exceed those of other digital modalities due to requirements for: high resolution image acquisition (4k x 4k or better in order to be equivalent to film); high-capacity viewing workstations with multiple high-resolution (2k x 2.5k or 4k x 5k) monitors capable of displaying current and previous examinations simultaneously; and fast high-capacity picture archiving and communication system networks to support retrieval and display of multiple mammography examinations. To the extent that these features are not generally available even in filmless digital medical imaging departments with picture archiving and communication systems, they must be considered additional costs related to DR-M.

DR-M avoids most film usage, although access to a high-speed film printer is needed for patient transfers and film copy requests. Some film-related equipment (film dispensers, film processors, multiformat cameras, light boxes, multiviewers) can be eliminated with use of DR-M, but much more equipment must be added for digital image acquisition, processing, film printing, and archiving. Our analysis assumes CR-M images will be interpreted via hard copy (film) and that film will be the method of image storage. CR-M replaces film dispensers and processors with CR cassette delivery/reading systems and high-speed film printers; light boxes and multiviewers are unaffected.

Space requirements: DR-M is expected to reduce the space and staff required for film archiving and may increase mammography through-put sufficiently to reduce the number of examination rooms required. Space and staff for DM-related computer equipment must be added. CR-M is not expected to change space requirements.

Annual operating costs: DR-M is expected to reduce annual operating costs through reduction in film costs, chemical costs, and staff film-handling time before, during, and after imaging

procedures. Radiology technologist staffing is expected to decrease, while computer operator and physicist time is expected to increase. Equipment maintenance costs (contract or time and materials) are expected to be higher for DR-M and CR-M than for FSM. DR-M is not expected to *reduce* radiologist reporting time, but *not increasing* reporting time is considered to be an important practical requirement for DM systems.

Radiation dose: The sensitivity of computerized sensing devices may allow digital image acquisition (used by both DR-M and CR-M) to use less radiation than conventional image acquisition. Although current radiation doses are extremely low, it is recognized that no radiation exposure is completely without risk. Radiation doses dropped dramatically when photographic film replaced glass plates in radiology. Mammography doses were greatly reduced when industrial film was replaced with a film and screen combination and a further reduction is recognized to be desirable. However, because current doses are considered to present an extremely low risk for most patients, the health benefit (and hence the value) of reducing dose further is not expected to be large.

Chemical exposure: Filmless imaging is expected to reduce staff exposure to film-developing chemicals. Although daylight processing has eliminated most direct skin contact, some level of airborne exposure remains. Airborne levels of chemicals in medical imaging are far below established industrial safety limits and the degree of hazard is therefore believed to be very low, but staff with extreme skin sensitivity can experience difficulty. Filmless imaging might be capable of further reducing airborne exposure. As with radiation dosage, it is clear that while eliminating airborne chemical exposure is desirable, the health benefits (and hence the value) from this change is not expected to be large.

Examination time: FSM examination times average approximately 12 to 15 minutes. DR-M avoids film-developing time (1 to 4 minutes) for all examinations and has been reported to reduce patient repositioning time. However, for DM systems with small detector size, more images may be needed for large-breasted women, reducing or eliminating examination time savings for these patients. Overall, digital image acquisition is expected to reduce both patient and staff time for image acquisition. Reduced staff time contributes to reduced operating costs and is modeled accordingly. Patient time savings are unlikely to be of practical importance, since for most mammography patients any reduction in examination time is minimal relative to the total time needed to attend for screening (including travel to and from the mammography site).

Repeat examinations: Examinations may be repeated because of poor image quality or because films could not be found when wanted, and eliminating repeat examinations has long been cited as a benefit of filmless imaging. It is possible to routinely achieve minimal rates of film loss in a film-based medical imaging department[53], making it inappropriate to count a reduction in lost films as a benefit achievable only with DR-M. However, DR-M systems may offer a reliable method of avoiding repeat exams due to lost images for medical imaging departments that have not, in practice, succeeded in minimizing film losses with conventional systems. DR-M and CR-M digital acquisition systems may be less subject to poor image quality than FSM, but are susceptible to other equipment failures that necessitate repeat examinations.

Diagnostic accuracy: At currently available image quality, digitally acquired mammography images have lower spatial resolution but more contrast information than conventional (film)

images. The potential for manipulation of digital images (zoom, brighten, contrast adjust, etc.) may nonetheless permit improvements in radiological diagnosis. CAD has also been reported to improve diagnostic accuracy of FSM, but has not been widely used in routine clinical practice.

Teleradiology: Electronic transmission of diagnostic images between physically distant sites could improve the quality of mammography services, particularly in remote and rural communities. Special equipment would be required, making the evaluation of teleradiology a question separate from that of DM, but teleradiology is an important potential benefit of DM.

Table 6: Studies providing cost information

Cost Category	**Study Providing Information (first author)**
Capital equipment	• Cox[43] (1999, DR-M US$250,000 to US$500,000) • Cupples[44] (DR-M ≈ US$250,000 in 1996, excl. workstation) • Dhaenens[11] (DR-M ≈ US$500,000 in 2000) • ECRI[45] (GE Senographe 2000D, ≈ US$400,000-500,000 in March 2000) • Hiatt[47] (2000, FSM cost ≈ US$50,000, DM cost ≈ US$102,000 • Johnson[48] (2001, FSM cost ≈ US$116,000; DR-M cost US$200,000 to US$400,000) • Nields[49] (2001, *additional* DR-M cost of US$240,000) • Roldan[51] (1996, 1992 pesetas, amortized costs per procedure) • Simonetti[52] (1998, workstation cost ≈ US$100,000) • Warburton[53](1995, PACS upgrade costs at least US$100,000)
Space requirements	• No information found
Annual operating costs	• Johnson[48] (2001, DM maintenance costlier than FSM) • Roldan[51] (1996, costs per procedure, 1992 pesetas; additional maintenance costs estimated at 5% of purchase price) • GE[46] (2001, reduced film costs by US$128,000 per year for 10,000 mammography examinations). • Warburton[53] (1995, technologist and film archive staffing reduced, PACS operator and physicist time increased)
Examination time	• O'Riordan[50] (2001, reduced time by 5.3 minutes) • GE[46] (2001, reduced time by 6.3 minutes)
Repeat examinations	• GE[46] (2001, reduced repeats by 1.48% of total) • O'Riordan[50] (2001, reduced repeats by 3% of total) • Roldan[51] (1996, reduced repeats by 6% of total)

5.2 Primary Economic Analysis

5.2.1 Methods

Any health technology must show acceptable technical and clinical performance before costs become important. This section of our review addresses costs for filmless DR-M, or hybrid CR-M systems, assuming that technical and clinical equivalence to conventional FSM either has been achieved, or is near enough to being achieved, that costs are beginning to be relevant to public policy in Canada. DR-M is licensed for mammographic use in Canada and the US. CR-M is currently licensed for mammographic use in Europe and Japan but not in Canada or the US. Until clinical equivalence is demonstrated in routine clinical practice, however, FSM remains the technology of choice.

The costs described here pertain to both screening and diagnostic mammography. The primary perspective taken for our analysis is that of a universal medicare program responsible for all capital and operating costs for mammography, including radiologist salaries or fees. Costs and benefits are considered from the viewpoint of society as a whole, recognizing that the essential purpose of publicly-funded health care in Canada is to maintain and improve the health of Canadians in a cost-effective manner. All costs, both monetary and intangible, are intended to be included, regardless of whether (in the current Canadian system) they would actually be paid by government, by a regional or local health authority, or by private parties. (For mammography, the only significant private "cost" is the time and expense required for patients to attend for the procedure and the discomfort or anxiety induced by it.)

This review describes and synthesizes the available research evidence in order to present an *ex ante* cost-minimization analysis, comparing the costs of providing mammography services using conventional (FSM), digital (DR-M), or hybrid (CR-M) systems. The use of cost-minimization analysis is based on the assumption that all of these technologies provide clinically equivalent mammography service. These cost estimates are therefore not relevant for decision-makers until DR-M and/or CR-M can be conclusively shown to provide mammography at least equal in quality to FSM. It is implicitly assumed that no reduction in accuracy is clinically acceptable. Since no improvement in accuracy has yet been demonstrated in routine practice, equivalent quality is assumed to be the most likely situation.

The use of cost-minimization analysis also means that the potential benefits of DR-M and/or CR-M are not currently considered to be significant for decision-makers, as benefits have not yet been demonstrated in routine clinical practice. These include potential reduction: in radiation dose (DR-M and CR-M), in examination times (DR-M only), and in exposure to film-related chemicals for staff (DR-M only). The potential for teleradiology with DR-M (and possibly with CR-M) has not been valued or modelled in this analysis, as significant additional equipment is required for teleradiology.

For simplicity, costs that are not expected to be affected by the technology used for mammography have been omitted from our modelled *ex ante* costs. This applies to radiologist salaries or fees, and to private costs (borne by patients or others). It is assumed that the technology used would not affect radiologist work times or radiologist fees, since achieving reporting times similar to FSM is part of achieving clinical equivalence and clinical acceptability

for DR-M. Similarly, private costs (primarily the time and expense of patients attending for mammography) are not expected to be materially changed by the technology used.

This synthesis of the available evidence in order to model costs for FSM and alternatives employs standard economic evaluation methodology.[54,55] The analysis reported is an *ex ante* cost-minimization analysis, the same method used for the BC digital imaging pilot project in the early 1990s.[53,56-58] Modelled costs are in 2002 Canadian dollars.

In this analysis, known cost and benefit categories were listed, and best available information was used to model likely quantities and prices for each category. Estimated capital and operating costs for FSM, DR-M, and CR-M were calculated. Capital costs were annualized (converted to equal annual payments that pay off both principal and interest over the equipment's useful life) assuming a seven-year equipment life and a 5% discount rate (to reflect the social discount rate in the absence of inflation). Annualized capital costs were then added to annual operating costs to produce total annualized capital and operating costs. Sensitivity analysis was used to test the robustness of the results to plausible variations in costs or benefits. Minimum, expected, and maximum costs are shown for each type of system, and a 3% discount rate was also modelled. Assumptions and calculations are described below.

5.2.2 Results and discussion

Modelled costs and effects: Table 7 shows estimated annual costs for FSM, DR-M and CR-M. Appendix 3 shows detailed calculations.

Capital equipment: FSM and DR-M system costs in 2002 Canadian dollars were estimated from the available literature. DM costs were assumed to range from US$200,000 to US$400,000 without a review workstation and US$300,000 to US$500,000 with a review workstation; all estimates assume a review workstation is required. No direct evidence was found regarding picture archiving and communication system upgrade costs, though many authors referred to the need for higher-speed networks and enhanced image storage capacity to support mammography. Based on the BC digital imaging pilot project[53], picture archiving and communication system upgrade costs were modelled at US$100,000 (minimum cost), US$250,000 (expected cost), and US$350,000 (maximum cost). These estimates were adjusted for inflation (2% per year) and converted to Canadian dollars at the exchange rate of US$1.00 = C$1.60.[59]

Total FSM capital costs range from C$147,000 to C$217,000; DM costs range from C$653,000 to C$1.4 million. The wide range in DM costs reflects the state of the technology; technical requirements and equipment prices vary significantly, both between manufacturers and between specific clinical sites.

Equipment costs for CR-M were assumed to be the same as FSM based on the BC digital imaging pilot project.[53] In a new department, savings from lower-power radiation generators and elimination of multiformat cameras are expected to be sufficient to cover the cost of CR-M cassettes, readers, network equipment, and high-speed film printers.

As has been true for computer equipment in general, capital costs for digital equipment (required for DR-M and CR-M systems) can be expected to decline in real terms over time, while

Table 7: Mammography costs-2002 Canadian dollars

	Minimum Costs			Expected Costs			Maximum Costs			SA - 3% Discount Rate		
	FSM	**DR-M**	**CR-M**	**FSM**	**DR-M**	**CR-M**	**FSM**	**DR-M**	**CR-M**	**FSM**	**DR-M**	**CR-M**
Annual Costs												
Equipment Amortization	25,384	112,817	25,384	31,025	183,327	31,025	37,512	239,736	37,512	28,814	170,265	28,814
Equipment Maintenance	7,344	65,280	10,282	8,976	109,616	12,566	10,853	143,344	15,194	8,976	109,616	12,566
Staff Wages and Benefits	228,660	153,904	228,660	238,793	201,640	238,793	264,124	280,562	264,124	238,793	201,640	238,793
Film-related supplies	54,753	2,738	54,753	76,654	3,833	76,654	98,555	4,928	98,555	76,654	3,833	76,654
Repeat examinations	6,323	1,674	1,595	10,663	4,984	3,590	18,497	10,029	6,231	10,597	4,854	3,568
Total Annual Costs	**322,463**	**336,412**	**320,674**	**366,111**	**503,400**	**362,628**	**429,541**	**678,598**	**421,616**	**363,834**	**490,207**	**360,395**
Extra cost (savings) from FSM		13,948	-1,790		137,289	-3,483		249,057	-7,925		126,373	-3,438
% extra cost (savings) from FSM		4.3%	-0.6%		37.5%	-1.0%		58.0%	-1.8%		34.7%	-0.9%
Amortization Period (years)	7	7	7	7	7	7	7	7	7	7	7	7
Discount Rate	5%	5%	5%	5%	5%	5%	5%	5%	5%	3%	3%	3%
Maintenance as a % of capital cost	5%	10%	7%	5%	10%	7%	5%	10%	7%	5%	10%	7%
Repeat examination rate	2.0%	0.5%	0.5%	3.0%	1.0%	1.0%	4.5%	1.5%	1.5%	3.0%	1.0%	1.0%

FSM = Conventional film-screen mammography
DR-M = Filmless digital mammography
CR-M = Computed radiography mammography, hybrid system using digital acquisition with film for reporting, archiving
SA = Sensitivity analysis
Expected useful life of equipment is 7 years.

equipment capabilities can be expected to improve over time. Future equipment can therefore be expected to be more cost-effective than current equipment. The expectation of better cost-effectiveness in the future provides a strong rationale for delaying acquisition of DR-M systems.

Space requirements: No information was found on department space saving due to DR-M and any net space reduction is expected to be small. All estimates assume no material net space saving.

Annual operating costs: Maintenance costs have been modelled at 5% of capital cost for FSM, 10% of capital cost for DR-M, and 7% of capital cost for CR-M, based on Johnson,[48] Roldan,[51] and Warburton.[53]

Staff costs for CR-M are expected to be the same as for FSM. The literature reports very little information concerning staff costs for DR-M, so these costs were modeled based on GE,[46] Roldan et al.,[51] and the BC digital imaging pilot project.[53] DR-M is assumed to save between 0.25 and 1.0 full time equivalent (FTE) radiology technologist positions (when compared to either FSM or CR-M), at an average salary and benefit cost of C$27.60 per hour in 2002. This amounts to a reduction of between 11% and 44% of expected staffing of 2.25 FTEs. DR-M is also assumed to reduce film archive staffing by between 0.25 and 1.0 FTE clerk positions, at an average salary and benefit cost of C$16.10 per hour. Finally, DR-M is assumed to increase picture archiving and communication system computer operator staffing by between 0.1 and 0.35 FTEs (hourly salary/benefits $18.40 per hour) and to increase physicist staffing by between 0.1 and 0.35 FTEs (hourly salary/benefits $36.80 per hour).

Film-related savings were estimated from information supplied by GE.[46] Savings of US$128,000 in 2001 at a large three-scanner facility providing 10,000 mammograms annually were prorated for a one-scanner facility, adjusted for inflation, and converted to Canadian dollars. Expected savings ranged from C$52,000 to C$94,000 per year. Total film costs were calculated for FSM, CR-M and DR-M systems by assuming that DM avoided 95% of FSM or CR-M film costs (DR-M systems require some film for patient transfers and film copy requests.)

Modelled operating costs have been based on the assumption that shorter DR-M examinations would reduce staff costs (for instance by allowing annual hours of machine operation to be reduced) but would not affect annual volumes (assumed to average about 3,500 exams per machine per year). For single-scanner mammography facilities serving a designated catchments area, increasing scan volumes and access might increase inappropriate use of the technology. Large, multiple-scanner facilities might be able to use DR-M to increase exam volumes sufficiently to reduce the number of machines needed at the facility, but this has not been modelled as it would likely affect only a few facilities in Canada.

Examination time: Estimated staff time savings of 0.25 to 1.0 FTEs were based on expected examination time reductions of 10% to 44% per procedure (FSM average examination time of 12 to 15 minutes). The minimum estimate reflects the possibility that little reduction in staff time may be realized in practice, based on the estimates by Roldan et al. (staff costs were reduced by only 2.7% with DR-M).

Repeat examinations: DR-M and CR-M were assumed to prevent repeat examinations of 1.5% and 3.0% of total (2% expected), based on the available literature. Estimated repeat exam costs were added to all systems.

5.2.3 Conclusions

Total annualized capital and operating costs for a single DR-M system are shown to be between C$14,000 (4%) and C$249,000 (58%) more than FSM in the main scenarios and C$126,000 (35%) more in the sensitivity analysis (which tests a 3% discount rate). Expected extra costs were C$137,000 (38%). The higher costs for DR-M equipment purchase and maintenance were only partly offset by lower costs for staff, film-related supplies and repeat exams. Refining staff cost savings estimates based on actual data is a priority, since significantly larger staff savings could results in overall DR-M costs being lower than FSM or CR-M.

CR-M has equivalent total costs to FSM and exactly the same annual costs as FSM except for maintenance and repeat examinations. Refining the estimates for maintenance costs and frequency of repeat examinations based on local information would be desirable, as these costs will determine whether FSM or CR-M has minimum costs in a particular setting.

6 CONCLUSIONS

In summary, what do the potential advantages and disadvantages of DM mean for patients, radiologists, institutions and health care payers?

Technical assessment: DM offers a number of potential benefits but most of these have yet to be realized in a clinical setting. A significant benefit for women would be shorter examination times; there is also a prospect of reduced radiation dose although its significance is unclear. Advantages for health professionals and institutions are the removal of the limitations and procedural burdens of dealing with X-ray film, including archiving, and the use of computer-based systems to assist with diagnosis. DM offers advantages through the ability to manipulate images and to transmit them, including the potential for telemammography. However, available DM systems also require technical improvements to achieve its full benefits.

Clinical assessment: Limited published studies showed the ability to detect cancer is comparable for both DM and FSM; large studies are needed to demonstrate any clinical advantages of DM.

Economic assessment: DR-M has significantly higher annualized costs than either FSM or CR-M. Potential clinical benefits (improved diagnostic accuracy, lower radiation dose) of DM for patients, institutions and payers have not yet been demonstrated. Reductions in examination time are expected with DR-M, but do not significantly affect the total time needed by patients. Operating cost savings from shorter examination times are not sufficient to offset higher capital costs. Radiologist reporting times for DR-M are currently greater than for FSM or CR-M systems; DR-M will not be clinically acceptable until reporting times are equivalent to film systems. At current prices, DR-M adds significantly to costs and therefore, in order to demonstrate an advantage, must demonstrate significant clinical, operational, and/or other benefits. Based on our finding that DR-M is currently, at best, clinically equivalent to either FSM or CR-M, the minimum-cost system would be preferred, therefore conventional FSM remains the preferred technology. CR-M has costs equivalent to conventional FSM and, once acceptable clinical performance is demonstrated, may be preferable to DR-M.

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Appendix 1: Literature Search Strategies

Legend:
exp = explode, i.e. retrieve MeSH term and narrower MeSH terms
sh = Medical Subject Heading (MeSH)
tw = textword (includes words from titles and abstracts and keywords)
hw = heading word
kw = keywords
mc = major concepts
cc = concept codes
pt= publication type

DATABASES	LIMITS	KEYWORDS
Ovid Technologies Inc. MEDLINE® (Mid 1998 – July week 3 2001) MEDLINE® (1966 – August week 2 2001)	1990+ Human Performed July 31, 2001 Performed August 20, 2001	1. mammography.sh. 2. (mammography OR mammogram?).tw. 3. digital.tw. 4. Set 1 OR Set 2 5. Set 3 AND Set 4 6. (senographe OR lorad OR senoscan).tw. 7. (general electric medical OR hologic OR fischer).tw 8. Set 3 AND Set 7 9. Set 5 OR Set 6 OR Set 8 10. exp "sensitivity and specificity" 11. exp diagnostic errors 12. exp probability 13. reproducibility of results.sh. 14. Set 10: Set 13 15. (sensitivit? OR specificit? OR predict? value? OR false positive?).tw. 16. (false negative? OR false rate? OR likelihood ratio? OR receiver operat? curve? OR roc OR diagnostic standard? OR diagnostic error? OR odds ratio?).tw. 17. Set 15 OR Set 16 18. (clinical trial OR clinical trial, phase i OR clinical trial, phase ii OR clinical trial, phase iii OR

		clinical trial, phase iv OR meta-analysis OR controlled clinical trial OR randomized controlled trial OR multicenter study).pt. 19. exp clinical trials 20. (comparative study OR double-blind method OR random allocation).sh. 21. (random? OR controlled trial? OR controlled clinical trial? OR clinical trial? OR double blind?).tw. 22. (multicent? trial? OR multi cent? trial? OR meta analy? OR metaanaly? OR meta-analysis).tw. 23. (research integration OR research overview? OR quantitative review? OR quantitative overview? OR methodologic review? OR methodologic overview?).tw. 24. (systematic overview? OR systematic review? OR integrative research OR quantitative synthesis OR comparative stud? OR prospective stud? OR retrospective stud? OR single blind? OR triple blind? OR treble blind? OR dummy OR sham OR rct).tw. 25. Set 18: Set 24 26. Set 14 OR Set 17 OR Set 25 27. Set 9 AND Set 26 28. Limit Set 27 to (human and yr=1990-2001) 29. exp radiation dosage 30. exp scattering, radiation 31. (radiographic image enhancement OR quality control OR phantoms, imaging OR radiology information systems OR artifacts).sh. 32. (quality control? OR hard cop? OR soft cop? OR technical

		image quality OR image receptor?).tw. 33. (image display? OR detector? OR receptor contrast? OR spatial resolution OR noise OR artifact?).tw. 34. (archiv? OR scatter? radiation OR motion blur? OR geometric blur? OR geometric distortion? OR imaging phantom?).tw. 35. (receptor blur? OR modulation transfer function? OR mtf OR grid? OR compression? OR characteristic curve?).tw. 36. Set 29 OR Set 30 OR Set 31 OR Set 32 OR Set 33 OR Set 34 OR Set 35 37. Set 9 AND Set 36 38. Limit Set 37 to (human and yr=1990-2001) 39. exp guidelines 40. (guideline or practice guideline).pt. 41. guideline?.tw. 42. Set 39: Set 41 43. Set 9 AND Set 42 44. Limit Set 43 to (human and yr=1990-2001) 45. Set 28 OR Set 38 OR Set 44 46. Limit Set 45 to (human and yr=1990-2001) =Clinical/Technical results 47. mammography/ec 48. exp mammography 49. exp economics 50. exp quality of life 51. (economic? OR quality of life? OR cost? OR price? OR pricing OR expenditure? OR budget? OR qol OR qaly OR quality adjusted life year? OR discount? OR willingess to pay).tw. 52. Set 48 AND (Set 49: Set 51) 53. Set 47 OR Set 52 54. Limit Set 53 to (human

		and yr=1990-2001= Economic results)
CANCERLIT® (1975-May 2001)	1990+ Human	Same as above
HealthSTAR® (1987-June 2001)	1990+ Human	Same as above
EMBASE® (1988-2001 Week 30)	1990+ Human	1. mammography.sh. 2. (mammography OR mammogram?).tw. 3. digital.tw. 4. Set 1 OR Set 2 5. Set 3 AND Set 4 6. (senographe OR lorad OR senoscan).tw. 7. (general electric medical OR hologic OR fischer).tw. 8. Set 3 AND Set 7 9. Set 5 OR Set 6 OR Set 8 10. (diagnostic error OR reproducibility OR probability).sh. 11. (sensitivit? OR specificit? OR predict? OR value? OR false positive?).tw. 12. (false negative? OR false rate? OR likelihood ratio? OR receiver operat? curve? OR roc OR diagnostic standard? OR diagnostic error? OR odds ratio?).tw. 13. Set 10: Set 12 14. (comparative study OR controlled study OR randomized controlled trial OR prospective study OR retrospective study OR meta analysis OR clinical trial OR multicenter study OR phase 1 clinical trial OR phase 2 clinical trial OR phase 3 clinical trial OR phase 4 clinical trial).sh. 15. (random? OR controlled trial? OR controlled clinical trial? OR clinical trial? OR double blind?).tw.

		16. (double blind? OR multicent? trial? OR multi cent? trial? OR meta analy? OR metaanaly? OR meta-analysis).tw. 17. (research integration OR research overview? OR quantitative review? OR quantitative overview? OR methdologic review? OR methodologic overview?).tw. 18. (systematic overview? OR systematic review? OR integrative research OR quantitative synthesis OR comparative stud? OR prospective stud? OR retrospective stud? OR single blind? OR triple blind? OR treble blind? OR dummy OR sham OR rct).tw. 19. Set 14 : Set 18 20. Set 9 AND Set 13 21. Set 9 AND Set 19 22. (image enhancement OR image quality OR image display OR signal noise ratio OR quality control OR radiation dose OR radiation scattering OR artifact OR artifact reduction OR modulation transfer function OR compression OR digital filtering).sh. 23. (quality control? OR hard cop? OR soft cop? OR technical image quality OR image receptor?).tw. 24. (image display? OR detector? OR receptor contrast? OR spatial resolution OR noise OR artifact?).tw. 25. (archiv? OR scatter? radiation OR motion blur? OR geometric blur? OR geometric distortion? OR imaging phantom?).tw.

		26. (receptor blur? OR modulation transfer function? OR mtf OR grid? OR compression? OR characteristic curve?)tw. 27. Set 22: Set 26 28. Set 9 AND Set 27 29. practice guideline.sh. 30. guideline?.tw. 31. Set 29 OR Set 30 32. Set 9 AND Set 31 33. Set 20 OR Set 21 OR Set 28 OR Set 31 34. Limit Set 33 to (human and yr=19990-2001) = Clinical/Technical results 35. (economic aspect OR quality of life OR quality adjusted life year).sh. 36. (economic? OR quality of life? OR cost? OR price? OR pricing OR expenditure? OR budget? OR qol OR qaly OR quality adjusted life yeare? OR discount? OR willingness to pay).tw. 37. Set 9 AND (Set 35 OR Set 36) 38. Limit Set 37 to (human and yr=1990-2001) = Economic results
Biological Abstracts/RRM® (1989-June 2001)	1990+ Human	1. mammography.hw,kw,mc. 2. (mammography OR mammogram?).tw. 3. digital.tw. 4. Set 1 OR Set 2 5. Set 3 AND Set 4 6. (senographe OR lorad OR senoscan).tw. 7. (general electric medical OR hologic OR fischer).tw. 8. Set 3 AND Set 7 9. Set 5 OR Set 6 OR Set 8 10. (sensitivity OR specificity OR diagnostic accuracy OR reproducibility).hw,kw,mc. 11. (sensitivity? OR specificit? OR predict? value? OR false

		positive?).tw. 12. (false negative? OR false rate? OR likelihood ratio? OR receiver operat? curve? OR roc OR diagnostic standard? OR diagnostic error? OR odds ratio?).tw. 13. Set 10 OR Set 11 OR Set 12 14. (clinical trial OR randomized trial OR prospective study OR randomized controlled trial OR multicenter study OR randomized clinical trial).hw,pt,kw,mc. 15. (random? OR controlled trial? OR controlled clinical trial? OR clinical trial? OR double blind?).tw. 16. (multicent? trial? OR multi cent? trial? OR meta analy? OR metaanaly? OR meta-analysis).tw. 17. (research integration OR research overview? OR quantitative review? OR quantitative overview? OR methodologic review? OR methodologic overview?).tw. 18. (systematic overview? OR systematic review? OR integrative research OR quantitative synthesis OR comparative stud? OR prospective stud? OR retrospective stud? OR single blind? OR triple blind? OR treble blind? OR dummy OR sham OR rct).tw. 19. Set 14 : Set 18 20. Set 13 OR Set 19 21. Set 9 AND Set 20 22. (image quality OR quality control OR radiation dose OR resolution OR noise).hw,kw,mc. 23. (quality control? OR hard cop?

		OR soft cop? OR technical image quality OR image receptor?).tw. 24. (image display? OR detector? OR receptor contrast? OR spatial resolution OR noise OR artifact?).tw. 25. (archiv? OR scatter? radiation OR motion blur? OR geometric blur? OR geometric distortion? OR imaging phantom?).tw. 26. (receptor blur? OR modulation transfer function? OR mtf OR grid? OR compression? OR characteristic curve?).tw. 27. Set 22: Set 26 28. Set 9 AND Set 27 29. (practice guidelines OR guidelines).cc,hw,kw. 30. guideline?.tw. 31. Set 29 OR Set 30 32. Set 9 AND Set 31 33. Set 21 OR Set 28 OR Set 32 34. Limit Set 33 to 1990-2001 = Clinical/Technical results 35. economics.mc. 36. (economic factors OR economic impact OR economic value OR cost OR cost analysis OR cost effectiveness OR cost savings OR cost-benefit analysis OR costs OR quality of life).mi,kw,mc. 37. (economic? OR quality of life? OR cost? Or price? OR pricing OR expenditure? OR budget? OR qol OR qaly OR quality adjusted life year? OR discount? OR willingness to pay).tw. 38. Set 9 AND (Set 35: Set 37) 39. Limit Set 38 to (human and year = 1990- 2001 = Economic results

INSPEC® (1987-2001 Week 28)	1990+ No "human" limits available in this database	1. (mammography OR mammogram?).tw. 2. digital.tw. 3. Set 1 AND Set 2 4. (senographe OR lorad OR senoscan.tw. 5. (general electric medical OR hologic OR fischer).tw. 6. Set 2 AND Set 5 7. Set 3 OR Set 4 OR Set 6 8. (sensitivit? OR specificit? OR predict? value? OR false positive?).tw. 9. (false negative? OR false rate? OR likelihood ratio? OR receiver operat? curve? OR roc OR diagnostic standard? OR diagnostic error? OR odds ratio?).tw. 10. Set 8 OR Set 9 11. (random? OR controlled trial? OR controlled clinical trial? OR clinical trial? OR double blind?).tw. 12. (multicent? trial? OR multi cent? trial? OR meta analy? OR metaanaly? OR meta-analysis).tw. 13. (research integration OR research overview? OR quantitative review? OR quantitative overview? OR research overview? OR methodologic review? OR methodologic overview?).tw. 14. (systematic overview? OR systematic review? OR integrative research OR quantitative synthesis OR comparative stud? OR prospective stud? OR retrospective stud? OR single blind? OR triple blind? OR treble blind? OR dummy OR sham OR rct).tw.

		15. Set 11: Set 14 16. (quality control? OR hard cop? OR soft cop? OR technical image quality OR image receptor?).tw. 17. (image display? OR detector? OR receptor contrast? OR spatial resolution OR noise OR artifact?).tw. 18. (archiv? OR scatter? radiation OR motion blur? OR geometric blur? OR geometric distortion? OR imaging phantom?).tw. 19. (receptor blur? OR modulation transfer function? OR mtf OR grid? OR compression ? OR characteristic curve?).tw. 20. Set 16: Set 19 21. guideline?.tw. 22. Set 10 OR Set 15 OR Set 20 OR Set 21 23. Set 7 AND Set 22 24. Limit Set 23 to ye =1990-2001 =Clinical/Technical results 25. (economic? OR quality of life? OR cost? OR price? OR pricing OR expenditure? OR budget? OR qol OR qaly OR quality adjusted life year? OR discount? OR willingess to pay).tw. 26. Set 7 AND Set 25 27. Limit Set 26 to year=1990-2001 = Economic results
Dialog® Conference Papers Index	Performed Sept. 27, 2001	1. digital 2. mammography 3. Set 1 AND Set 2/1990:2001= 82 references
Cochrane Collaboration and Update Software Cochrane Library on CD-ROM	2001, Issue 2	1. digital AND mammography 2. digital AND mammogram? 3. "digital mammography" (digital next to mammography) 4. "digital mammogram?" (digital next to mammogram?) 5. Set 1: Set 4 6. Limited to 1990-2001

PubMed	Performed Oct. 14, 2001	1. digital mammography [all fields] 2. (senographe OR lorad OR senoscan) ([all fields] 3. Set 1 OR Set 4 4. ("sensitivity and specificity" OR diagnostic errors OR reproducibility of results OR diagnostic errors) [MeSH terms] 5. (sensitivity OR specificity OR predictive value OR predictive values OR false positive OR false negatives OR false negative OR likelihood ratio OR likelihood ratios OR receiver operating curve OR receiver operating curves OR roc OR diagnostic standard OR diagnostic standards OR diagnostic error OR diagnostic errors OR odds ratio OR odds ratio)[all fields] 6. (clinical trial OR clinical trial, phase i OR clinical trial, phase ii OR clinical trial, phase iii OR clinical trial, phase iv)[Publication Type] 7. (meta-analysis OR controlled clinical trial OR randomized controlled trial OR multicenter study)[Publication Type] 8. (clinical trials OR comparative study OR double-blind method OR random allocation)[MeSH terms] 9. (random OR randomized OR randomized OR controlled clinical trials OR clinical trial OR clinical trials OR double blind OR double blinded OR multicentre trials OR multicenter trial OR metaanlaysis OR metaanalyses OR meta-analysis OR meta-analyses OR research integration OR research overviews OR quantitative

		review OR quantitative reviews OR research overview OR methodological overviews OR systematic reviews OR stystematic overviews OR integrative research OR quantitative synthesis OR comparative study OR comparatives studies OR rct OR rcts OR prospective study OR retrospective study OR single blind OR single blinded OR triple blind OR triple blinded OR treble blinded OR dummy OR sham)[Text Word] 10. Set 3 AND (Set 4: Set 9) 11. Limited to Publication Date from 1990/01/01 to 2001/11/01
Google™, websites of health technology and near-health technology assessment websites; specialized databases such as those of the University of York NHS Centre for Reviews and Dissemination; trial registers; clinical practice guideline databases; database of regulatory agencies such as Health Canada; manufacturers' websites; websites of associations and societies, such as the Radiological Society of North America (RSNA).		

Update Literature Search

Legend:

! = explode, or retrieve all narrower MeSH as well as broader MeSH
de = Medical Subject Heading
ti,ab = words from titles and abstracts
() = words are adjacent backwards or forwards
ud = update
rd = reduce duplicates
? = truncation symbol

DATABASES	LIMITS	KEYWORDS
Dialog® OneSearch® MEDLINE® (File 154), CANCERLIT® (File 159)	Human Update June 2001 – May 2002	1. mammography/de 2. (mammography OR mammogram?)/ti,ab 3. digital/ti,ab. 4. Set 1:Set 2) 5. Set 3 AND Set 4 6. (senographe OR lorad OR senoscan)/ti,ab 7. (general() electric() medical OR hologic OR fischer OR fuji()medical)/ti,ab 8. Set 3 AND Set 7 9. Set 5 OR Set 6 OR Set 8 10. "sensitivity and specificity"! 11. diagnostic errors! 12. probability! 13. reproducibility of results/de 14. Set 10 : Set 13 15. (sensitivit? OR specificit? OR predict?() value? OR false() positive?)/ti,ab 16. (false() negative? OR false() rate? OR likelihood() ratio? OR receiver() operat?() curve? OR roc OR diagnostic() standard? OR diagnostic() error? OR odds() ratio?)/ti,ab 17. Set 15 OR Set 16 18. dt= (clinical trial OR clinical trial, phase i OR clinical trial, phase ii OR clinical trial, phase

		iii OR clinical trial, phase iv OR meta-analysis OR controlled clinical trial OR randomized controlled trial OR multicenter study) 19. clinical trials! 20. (comparative study OR double-blind method OR random allocation)/de 21. (random? OR controlled() trial? OR controlled() clinical() trial? OR clinical() trial? OR double() blind?)/ti,ab 22. (multicent?() trial? OR multi() cent?() trial? OR meta() analy? OR metaanaly? OR meta-analysis)/ti,ab 23. (research() integration OR research() overview? OR quantitative() review? OR quantitative() overview? OR methodologic() review? OR methodologic()overview?)/ti,ab 24. [systematic() overview? OR systematic() review? OR integrative() research OR quantitative() synthesis OR comparative() stud? OR prospective() stud? OR retrospective() stud? OR single() blind? OR triple() blind? OR treble() blind? OR dummy OR sham OR rct?) /ti,ab 25. Set 18 : Set 24 26. Set 14 OR Set 17 OR Set 25 27. Set 9 AND Set 26 28. Set 27/human AND ud=200106:200205 29. radiation dosage! 30. scattering, radiation! 31. (radiographic image enhancement OR quality control OR phantoms, imaging OR radiology information

		systems OR artifacts)/de 32. (quality control? OR hard cop? OR soft cop? OR technical image quality OR image receptor?)/ti,ab 33. (image display? OR detector? OR receptor contrast? OR spatial resolution OR noise OR artifact?)/ti,ab 34. (archiv? OR scatter? radiation OR motion blur? OR geometric blur? OR geometric distortion? OR imaging phantom?)/ti,ab 35. (receptor blur? OR modulation transfer function? OR mtf OR grid? OR compression? OR characteristic curve?)/ti,ab 36. Set 29: Set 35 37. Set 9 AND Set 36 38. Set 37/human AND ud=200106:200205 39. guidelines! 40. dt=(guideline or practice guideline) 41. guideline?/ti,ab 42. Set 39: Set 41 43. Set 9 AND Set 42 44. Set 43/human AND ud=200106:200205 45. Set 28 OR Set 38 OR Set 44 = Clinical 46. Set 45 from 154 =(Clinical/Technical references from MEDLUNE® 47. Set 45 from 159 = Clinical/Techncial from CANCERLIT®) 48. digital/ti,ab 49. mammography(l)ec AND Set 48 50. mammography! AND Set 48 51. economics! 52. quality of life! 53. (economic? OR quality of life? OR cost? OR price? OR pricing

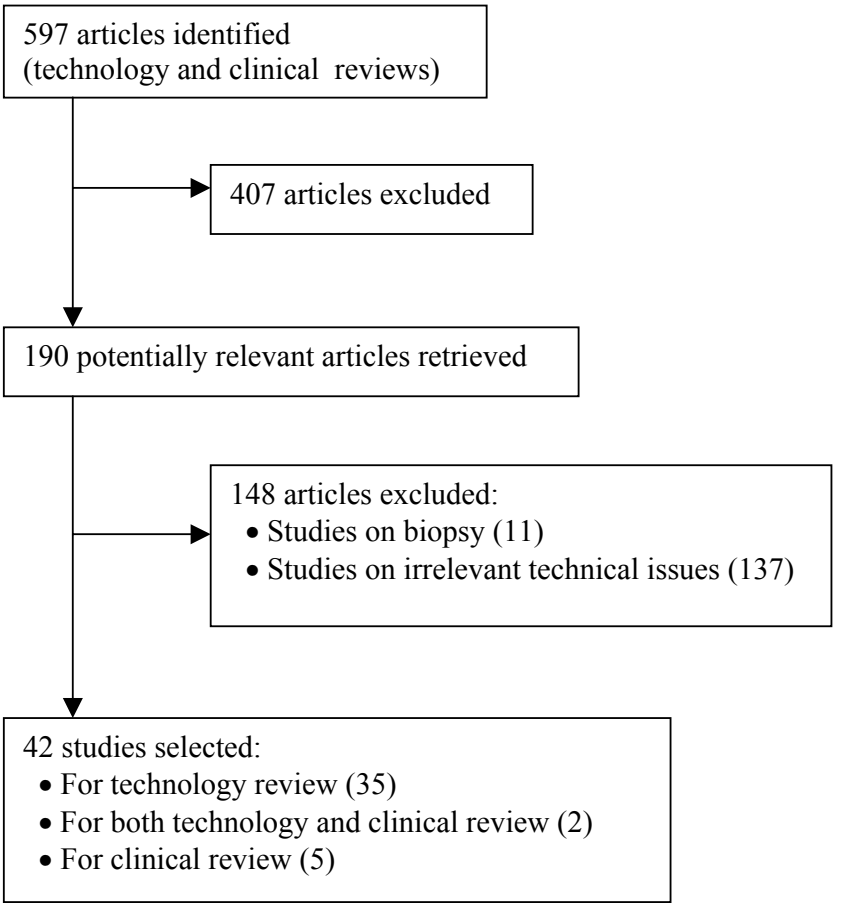
		OR expenditure? OR budget? OR qol OR qaly OR quality adjusted life year? OR discount? OR willingess to pay)/ti,ab 54. Set 50 AND (Set 51:Set 53) 55. Set 49 OR Set 54 56. Set 55 limit/human AND ud=2001006:200205 57. Set 56 from 154 = (Economic references from MEDLINE®) 58. Set 56 from 19 = (Economic references from CANCERLIT®).
EMBASE® (File 72)	August 2001 – May 2002 Human	59. (diagnostic error OR reproducibility OR probability)/de 60. (comparative study OR controlled study OR randomized controlled trial OR prospective study OR retrospective study OR meta analysis OR clinical trial OR multicenter study OR phase 1 clinical trial OR phase 2 clinical trial OR phase 3 clinical trial)/de 61. (image enhancement OR image quality OR image display OR signal noise ratio OR quality control OR radiation dose OR radiation scattering OR artifact OR artifact reduction OR modulation transfer function OR compression OR digital filtering)/de 62. practice guideline/de 63. guideline?/ti,ab 64. Set 21:Set 24 65. Set 29:Set 35 66. Set 59:Set 63 67. Set 9 AND (Set 17 OR Set 64 OR Set 65 OR Set 66) 68. Set 67/human AND ud=200108:200205

		69. Set 68 from 72 = (Clinical/Technical references from EMBASE®) 70. (economic aspect OR quality of life OR quality adjusted life year)/de 71. Set 50 AND (Set 70 OR Set 53) 72. Set 49 OR Set 71 73. Set 72/human AND ud=200108:200205 74. Set 73 from 72 = (Economic references from EMBASE®)
Biosis Previews® (File 55)	Human July 2001 - May 2002	75. (sensitivity OR specificity OR diagnostic accuracy OR reproducibility)/de 76. (clinical trial OR randomized trial OR prospective study OR randomized controlled trial OR multicenter study OR randomized clinical trial)/de 77. (image quality OR quality control OR radiation dose OR resolution OR noise)/de 78. (practice guidelines OR guidelines)/de 79. Set 75: Set 78 80. Set 9 AND (Set 17 OR Set 64 OR Set 65 OR Set 41 OR Set 79) 81. Set 80/human AND ud=200107:200205 82. Set 81 from 5 =(Clinical/Technical references from Biosis Previews®) 83. economics/de 84. (economic factors OR economic impact OR economic value OR cost OR cost analysis OR cost effectiveness OR cost savings OR cost-benefit analysis OR costs OR quality of life)/de 85. Set 50 AND (Set 83 OR Set 84 OR Set 53) 86. Set 2 AND Set 3 AND

		(Set 84 OR Set 83 OR Set 53) 87. Set 85 OR Set 86 88. Set 87/human AND ud=200107:200205 89. Set 88 from 5= (Economic references from Biosis Previews®)
INSPEC®	July 2001 – May 2002 No "human" limits in this database	90. Set 9 AND (Set 17 OR Set 64 OR Set 31 OR Set 32 OR Set 33 OR Set 34 OR Set 35 OR Set 41) 91. Set 90 AND ud=200107:200205 92. Set 91 from 4 = (Clinical/technical references from INSPEC®) 93. Set 9 AND Set 53 94. Set 92 AND ud=200107:200205 = (Economic references from INSPEC®) 95. Set 94 from 4 = (Economic references from INSPEC®)
		96. Set 46 OR Set 47 OR Set 69 OR Set 82 OR Set 92 97. rd Set 96 = Unique clinical/technical references
		98. Set 57 OR Set 58 OR Set 74 OR Set 89 OR Set 95 99. rd Set 98 = Unique economic references

Appendix 2: Flow Chart of Selection of Relevant Studies

* Numbers reflect the total number of studies for the technical and clinical review combined.



Appendix 3: Detailed Calculations

Calculation of equipment costs	FSM	DR-M	CR-M	FSM	DR-M	CR-M	FSM	DR-M	CR-M	Inflation rate:
	Minimum	Minimum	Minimum	Expected	Expected	Expected	Maximum	Maximum	Maximum	2.0%
US $ Cost of mammography equipment	90,000	300,000	90,000	110,000	400,000	110,000	133,000	500,000	133,000	
US $ Cost for PACS upgrade		100,000			250,000			350,000		
Year for above cost	2001	2001	2001	2001	2001	2001	2001	2001	2001	Current year
US $ Cost in 2002, mammog. eqpt *	91,800	306,000	91,800	112,200	408,000	112,200	135,660	510,000	135,660	2002
US $ Cost in 2002, PACS upgrade *		102,000			255,000			357,000		
C $ Cost in 2002, mammog. eqpt.	146,880	489,600	146,880	179,520	652,800	179,520	217,056	816,000	217,056	
C $ Cost in 2002, PACS upgrade		163,200			408,000			571,200		US $ XR:
C $ Cost in 2002, TOTAL	146,880	652,800	146,880	179,520	1,060,800	179,520	217,056	1,387,200	217,056	1.6

* inflation-adjusted at 2% per year

DR-M costs assume range of $200k to $400k without workstation, $300k to $500k with workstation.

CR-M capital costs same as conventional; savings from lower-power radiation generators and elimination of multiformat cameras are sufficient to purchase necessary CR-M cassettes, readers, network equipment, high-speed film printers.

DR-M is assumed to save between 0.1 and 1.0 full time equivalent (FTE) radiology technologist positions (when compared to annual staffing for either FSM or CR-M), at an average annual salary and benefit cost of C $60,000 per year in 2002.

Appendix 3: Detailed calculations (cont'd)

Calculation of Staff Costs	FSM Minimum	DR-M Minimum	CR-M Minimum	FSM Expected	DR-M Expected	CR-M Expected	FSM Maximum	DR-M Maximum	CR-M Maximum
Technologist FTEs	2.15	1.15	2.15	2.25	1.50	2.25	2.50	2.25	2.50
Difference from FSM FTEs		-1.00			-0.75			-0.25	
Technologist salary & benefit costs	116,188	62,147	116,188	121,592	81,061	121,592	135,102	121,592	135,102
Film Archive Clerk FTEs	3.23	2.23	3.23	3.38	2.63	3.38	3.75	3.50	3.75
Difference from FSM FTEs		-1.00			-0.75			-0.25	
Clerk salary & benefit costs	101,664	70,140	101,664	106,393	82,750	106,393	118,214	110,333	118,214
PACS Computer Operator FTEs	0.00	0.10	0.00	0.00	0.25	0.00	0.00	0.35	0.00
Difference from FSM FTEs		0.10			0.25			0.35	
PACS Operator salary & benefit costs	0	3,603	0	0	9,007	0	0	12,610	0
Physicist FTEs	0.15	0.25	0.15	0.15	0.40	0.15	0.15	0.50	0.15
Difference from FSM FTEs		0.10			0.25			0.35	
Physicist salary & benefit costs	10,808	18,014	10,808	10,808	28,822	10,808	10,808	36,027	10,808
Total salary and benefit costs	228,660	153,904	228,660	238,793	201,640	238,793	264,124	280,562	264,124

Technologist and Archive Clerk hours		
Days per year	365	
Minus weekend days	-104	
Minus statutory holidays	-12	
Minus annual vacation days	-10	
Minus annual sickness days	-3	
Annual days actually worked	236	
Annual hours actually worked	1,652	
Paid annual hours	1,958	(union agreement)
Annual hours of scanner operation	1,743	
FTEs needed to staff 1 shift	1.12335	

Technologist Clerk FTE Savings %			
	Minimum	Expected	Maximum
% Reduction:	10%	30%	40%
FTE reduction:	-0.23	-0.68	-0.90
Modeled as:	-0.25	-0.75	-1.00
% modeled:	-11.1%	-33.3%	-44.4%

	Base Hourly	Incl. Benefits	Annual incl. benefits		
Base salary, Technologist 4	24.00	27.60	54,041	per year	Mammography Tech.
Base salary, Clerk 4	14.00	16.10	31,524	per year	File Room Clerk
Base salary, Computer operator	16.00	18.40	36,027	per year	PACS computer operator
Base salary, Physicist	32.00	36.80	72,054	per year	Medical Imaging Physicist

GE Medical Systems, 2001, reported exam time reduced 44% for diagnostic exams, 30% for screening exams.
Staff benefits approximated at 15% of salary cost. A full time equivalent (FTE) is 1,958 paid hours per year.
PACS operator and physicist FTEs reflect mammography-related staffing.

Appendix 3: Detailed calculations (cont.)

Film-related savings			Assumption:			
DR-M saved US $	128,000		DR-M saves 95% of film costs			
in year	2001		(some film needed for patient transfers)			
for # of mammography exams	10,000	(3 scanners)				
US $ savings in 2002 for above exams	130,560					
C$ savings in 2002 for above exams	208,896	69,632	one scanner			
days per scanner per year	249		Average			
exams per day per scanner	10	18				
annual exams per scanner	2,490	4,482	3,486			
C $ saved, 2002, per scanner	52,015	93,627	72,821			
				Minimum	Expected	Maximum
FSM or CR-M film cost				54,753	76,654	98,555
DR-M film cost				2,738	3,833	4,928
DR-M film cost savings (95% of FSM)				52,015	72,821	93,627
GE Systems, 2001 reported annual savings of US $128,000 for centre with three scanners, two DR-M and one FSM.						
Source: GE Medical Systems, 2001.						