COMPARISON OF COLOUR MONITOR AND HIGH RESOLUTION GREYSCALE DIAGNOSTIC MONITOR USING DEDICATED PACS WORKSTATION ON COMPUTED RADIOGRAPH OF CHEST

BY

DR KHATRULNADA BT MD SAAD

Dissertation Submitted in Partial Fulfillment of the Requirements for Degree of Master of Medicine (Radiology)

UNIVERSITI SAINS MALAYSIA

UNIVERSITI SAINS MALAYSIA
2006

To

My husband;
Dr. Muhammad Rizal Abdul Rahim

My lovely daughters;
Husna Liyana and Hannan Syamimi

Thank you for the love, understanding, support and most of all, patience.

To

My parents
Thank you for the prayers

To

My friends;
Dr. Fatimah@Hartina and family,
Dr. Gurmit Kaur, Dr. Hasnah and Dr. Siti Nor Badriati.

Thank you for being there through my happy and difficult moments.

ACKNOWLEDGEMENTS

I would like to express deepest gratitude to the following individuals for their guidance, comments, advice and support during the preparation of this dissertation:

- Dr. Mohd. Ezane Aziz, supervisor of this dissertation, Head of Department of Radiology, Lecturer/Radiologist of Radiology Department, HUSM.

- Dr.Than Winn and Dr. Kamarul Imran Musa, Lecturers, Department of Community Medicine, HUSM.

- Dr. Rohaizan Yunus, Lecturer/Radiologist, Radiology Department, HUSM and Dr. Kartikasalwah Abdul Latif, Final year M.Med Radiology, HUSM, who exhibited patience and devotion in completing the tedious assignment, which was the most important part of this study.

- Associate Professor Dr. Ibrahim Lutfi Shuaib, my former supervisor and lecturer.

- Lectures/Radiologists in Radiology Department, HUSM.

- Mr. Nik Fauriza, Radiographer in Radiology Department HUSM

- Colleagues and all staff in Radiology Department, HUSM.

ABSTRAK

BAHASA MALAYSIA

Tajuk: Perbandingan di antara paparan komputer berwarna dan paparan komputer hitam putih yang mempunyai peleraian tinggi menggunakan sistem khusus stesen kerja PACS untuk radiograf dada berkomputer.

Latar belakang: Paparan berkomputer adalah alat yang penting dalam pengimejan digital. Paparan komputer hitam putih yang mempunyai peleraian tinggi adalah merupakan piawaian utama. Walaubagaimanapun, paparan komputer jenis ini adalah sangat mahal dan penggunaannya dalam situasi klinikal mungkin tidak menjimatkan. Maka, atas sebab kewangan, penggunaan sistem tanpa filem bagi keseluruhan hospital masih belum dapat diterima di HUSM. Paparan komputer berwarna adalah lebih menjimatkan, tetapi, sangat sedikit kajian dilakukan mengenai ketepatannya dalam menafsirkan radiograf berbanding paparan komputer hitam putih berpeleraian tinggi.

Tujuan: Kajian ini bertujuan untuk menentukan ketepatan diagnosis dan persetujuan di antara paparan komputer berwarna dan paparan komputer hitam putih berpeleraian tinggi, untuk radiograf dada berkomputer.

Metodologi: Kelulusan Jawatankuasa Etika Institusi telah diperolehi. Keizinan pesakit tidak diperlukan. Ini adalah kajian perbandingan keratan lintas yang dijalankan di Hospital Universiti Sains Malaysia(HUSM), Kubang Kerian, Kelantan. Semua radiograf dada berkomputer dari 1 Jun 2004 hingga 31 Disember 2005 digunakan sebagai sumber populasi. Terdapat 136 imej dada selepas saringan. Dua pemerhati digunakan untuk memerhati 136 radiograf dada berkomputer yang mengandungi 48 radiograf yang normal dan 88 radiograf yang tidak normal, menggunakan paparan komputer berwarna dan paparan komputer hitam putih pada masa yang berlainan di antara 3 hingga 4 minggu. Skor diberikan ke atas radiograf dada yang dilihat menggunakan borang yang disediakan. Analisis bagi kepekaan, spesifikasi, ketepatan dan kebolehpercayaan digunakan.

Keputusan: Kedua- dua pemerhati menunjukkan kepekaan sebanyak 74.8% dan spesifisiti yang bernilai 94.0% bagi paparan komputer hitam putih dan kepekaan sebanyak 69.2% dengan spesifisiti 94.1% untuk paparan komputer berwarna. Walaubagaimanapun kedua-duanya tidak menunjukkan perbezaan ketara dalam 95% konfiden interval. Pengiraan ketepatan menunjukkan 91.9% untuk paparan komputer hitam putih dan 91.5% untuk paparan komputer berwarna. Persetujuan untuk kedua-dua paparan komputer bagi pemerhati pertama, kedua dan kedua-duanya bagi semua kes yang tidak normal adalah dalam kadar yang teguh(k=0.748-0.767). Manakala persetujuan di antara kedua-dua pemerhati bagi paparan komputer hitam putih(k=0.599) dan berwarna (k=0.515) adalah dalam kadar yang sederhana.

Kesimpulan: Paparan komputer berwarna adalah sebanding paparan komputer hitam putih bagi penentuan radiograf dada yang tidak normal dalam kepekaan, spesifisiti, ketepatan dan kebolehpercayaan.

ABSTRACT

ENGLISH

Topic: Comparison of colour monitor and high resolution greyscale diagnostic monitor using dedicated PACS workstation on computed radiograph (CR) of the chest.

Background: Computers and monitors are the most important tools in digital imaging. High resolution greyscale diagnostic monitor is the current gold standard for soft copy display. However, this type of monitor is very expensive and its use in clinical practice may not be cost effective. Hence, for economical reason, a hospital-wide filmless system based on PACS equipped with workstation for viewing radiographs has not yet been accepted in HUSM. An alternative to the expensive diagnostic workstation monitor that is more cost-effective and can present comparable images must be considered. Colour monitor is considerably cheaper; however there were very few studies on the accuracy and reliability of colour monitor in the interpretation of radiographs in comparison to that of a high resolution greyscale monitor.

Objectives: The aim of this study is to determine the diagnostic accuracy and reliability of colour monitor compared to high resolution greyscale diagnostic monitor on CR chest.

Methodology: The institutional ethics committee approved the study; informed consent was not required. This study was a comparative cross sectional study and conducted in Hospital Universiti Sains Malaysia (HUSM), Kubang Kerian, Kelantan. All computed chest radiographs from 1 June 2004 to 31 December 2005 were used as source population. A total of 136 chest images remained after the screenings. Two observers reviewed 136 CR chest images comprising of 48 normal and 88 abnormal images using colour monitor and greyscale monitor at different occasions separated between 3 – 4 weeks. The detections were scored using a scoring form. Analysis of sensitivity, specificity, accuracy and reliability were used.

Results: Combination of both observers showed sensitivity of 74.8% and specificity of 94.0% for greyscale monitor and 69.2% sensitivity with 94.1% specificity for colour monitor. There was no statistical significant different for sensitivity and specificity between the two monitors at 95% confidence interval. The calculated accuracy was 91.9% for greyscale monitor and 91.5% for colour monitor. Intraobserver agreements for all the abnormalities were substantial for observer 1, observer 2 and both observers combined together (k=0.748-0.767). Moderate agreement were demonstrated between the observers for greyscale (k=0.599) and colour monitor (k=0.515).

Conclusion:

Colour monitor was comparable to high resolution greyscale diagnostic monitor in sensitivity, specificity, accuracy and reliability for detection of chest abnormalities.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ii

ABSTRAK iii

BAHASA MALAYSIA iii

ENGLISH v

TABLE OF CONTENTS vii

LIST OF TABLES x

LIST OF FIGURES. xi

ABBREVIATIONS xii

1.0 INTRODUCTION 1

2.0 LITERATURE REVIEW. 4

2.1 Picture archiving and communication system (PACS). 4

2.1.1 Soft copy versus hard copy. 9

2.1.2 Standard and guidelines. 11

2.2 PACS workstation. 14

2.2.1 Types of PACS workstation. 14

2.2.2 Display monitor. 20

2.2.3 Compression. 28

2.3 Computed radiograph (CR) of chest. 28

3.0 OBJECTIVES AND HYPOTHESIS 30

3.1 General Objective 30

3.2 Specific objectives 30

3.3 Null hypothesis 30

3.4 Research hypothesis........31

4.0 METHODOLOGY........32

4.1 Study design........32

4.2 Reference Population........32

4.3 Source Population........32

4.4 Sample Size........32

4.5 Study tools........33

4.5.1 Computed chest radiographic images........33

4.5.2 PACS Workstation........33

4.5.3 Colour monitor........34

4.6 Image selection........34

4.7 Image viewing........35

4.8 Statistical Analysis........37

4.8.1 Comparison of diagnostic accuracy of CR chest on colour monitor and high resolution greyscale monitor........38

4.8.2 Reliability measurement between colour monitor and high resolution greyscale diagnostic monitor........41

5.0 RESULTS........43

5.1 Descriptive analysis........43

5.2 Measures of diagnostic accuracy........47

5.3 Reliability measurement between colour monitor and high resolution greyscale diagnostic monitor........52

5.4 Interobserver agreement of colour monitor and high resolution greyscale diagnostic monitor....55
5.5 Analysis of agreement according to level of difficulties....57
5.6 Analysis of false positive....58
6.0 DISCUSSION....60
6.1 Comparison of diagnostic accuracy between greyscale diagnostic workstation and colour monitor....62
6.2 Determination of reliability between greyscale diagnostic workstation and colour monitor....66
6.3 Interobserver agreement....69
7.0 SUMMARY AND CONCLUSION....73
8.0 PROBLEMS AND LIMITATIONS....74
9.0 RECOMMENDATIONS....76
REFERENCES....77
APPENDICES....82

LIST OF TABLES

Table 1 : German Radiology Monitor Consensus 13

Table 2: Software functions for a Display Workstation. 15

Table 3 : Differences between LCD and CRT monitors. 23

Table 4: 2x2 Diagnostic table (cross tabulation) 39

Table 5: Measures of accuracy of a diagnostic test. 40

Table 6: Detailed description of chest abnormalities. 46

Table 7: Detection of chest abnormalities by observer 1. 47

Table 8: Detection of chest abnormalities by observer 2 48

Table 9: Detection of chest abnormalities by both observers. 49

Table 10: Sensitivity, specificity, PPV, NPV with confidence intervals, of grayscale and colour monitors. 50

Table 11: Intraobserver agreement between colour monitor and high resolution gray scale diagnostic monitor. 52

Table 12: Intraobserver agreement between colour monitor and high resolution gray scale diagnostic monitor for each category of chest abnormalities. 53

Table 13: Interobserver agreement. 55

Table 14: Interobserver agreement of colour monitor and high resolution gray scale diagnostic monitor in each category of chest abnormalities. 56

Table 15: Agreement according to level of difficulty (subtlety). 57

Table 16: Chest abnormalities; True-positive and false-positive cases 59

LIST OF FIGURES.

Figure 1: PACS infrastructure and network in Radiology Department, HUSM. 8

Figure 2: Diagnostic workstation...16

Figure 3: Review workstation...18

Figure 4: Analysis workstation..19

Figure 5: CRT monitors..25

Figure 6: The overall flow chart of the study. 42

Figure 7: General CR chest distribution 44

Figure 8: Frequency of distribution of specific chest abnormalities. 45

ABBREVIATIONS

AP	Anteroposterior
ACR	American College of Radiology
Cd/m^2	Candela per $meter^2$
CI	Confidence interval
CRT	Cathode ray tube
CR	Computed radiography
CT	Computed tomography
3-D	Three dimensional
DICOM	Digital Image Communication in Medicine
DSA	Digital subtraction angiography
Ft-Lt	Foot Lambert
GHz	Gigahertz
HUSM	Hospital Universiti Sains Malaysia
IMS	Image management system
ISU	Image storage unit
JPEG	Joint Photographic Expert Group
LAN	Local area network
LCD	Liquid crystal display
Lp/mm	Line pair per millimetre
LUT	Look up table
MB	Megabyte
MHz	Megahertz

MIU	Modality interphase unit
MP	Mega pixel
MRI	Magnetic resonance imaging
MTF	Modulation transfer function
NEMA	National Electrical Manufactures Association
NPV	Negative predictive value
PACS	Picture Archiving and Communication System
PC	Personal computer
PPV	Positive predictive value
RAID	Redundant array of independent disk
RAM	Random access memory
RN	Registration number
TFT	Thin film transistor

SECTION 1:

INTRODUCTION

1.0 INTRODUCTION

The interpretation of images in clinical radiology is changing rapidly from procedure based on film and light boxes to one based on computers and monitors. The transition has been accelerated by the introduction of digital imaging modalities and picture archiving and communication systems (PACS) (Hwang *et al*, 2003).

In the world of digital imaging, computers and monitors would be considered as the most important tools. High resolution greyscale cathode ray tube monitor (CRT) is the current gold standard for soft copy display (Fuchsjager *et al*, 2003) as it has been proven to have the ability to achieve acceptable accuracy (Cox *et al*, 1990, Ishigaki *et al*, 1996, Fuchsjager *et al*, 2003). However, this type of monitor is very expensive and its use in clinical practice may not be cost effective. The liquid crystal display (LCD) colour monitor which is relatively less expensive has not yet been accepted for medical applications for several reasons. The most important factors are due to its lower matrix size and degradation of greyscale. The other reasons include poor response speed, contrast ratio depends on viewing angle and poor stability.

Since the introduction of PACS in Radiology Department, HUSM in 2000 and implementation of computed radiography (CR) in 2002, the interpretation and report of plain radiographs were exclusively made on high resolution grey-scale diagnostic workstation. However, the diagnostic workstations available in the Radiology Department, HUSM are limited in number. HUSM, being an academic institution, plain radiographic viewing is the essence in radiology. As such increasing the number of high resolution greyscale diagnostic workstation should be considered for the achievement of optimal plain radiographic viewing and reporting. Even though this is the most ideal solution, the cost will be a financial burden to the hospital management.

Results of several previous studies in various areas of diagnostic imaging have shown that soft-copy image quality and the performance of soft copy reporting is similar or superior to conventional hard-copy imaging (Hayrapetian *et al*, 1989, Cox *et al*, 1990, Slasky *et al*, 1990, Ackerman *et al*, 1993, Thaete *et al*, 1994, Steckel *et al*, 1995, Ishigaki *et al*, 1996). Recent studies have shown more interest in comparing gray scale monitor with a considerably less expensive colour monitor. However, there were relatively very few studies pertaining to this issue. The available studies showed encouraging results where the LCD colour monitor had been accepted as comparable to gray scale monitor (Kolodny *et al*, 1999, Wu *et al*, 1999, Xu *et a*l, 1999, Doyle *et al*, 2002 and 2005, Sterling *et al*, 2003).

Implementing a PACS for other departments or hospital wide will require a costly investment if the expensive high resolution greyscale diagnostic workstations were to be used. Hence, for economical reason, a hospital-wide filmless system based on PACS equipped with workstations and a local area network (LAN) specialised for viewing radiographs has not yet been accepted in HUSM. An alternative to the expensive diagnostic workstation monitor that is more cost-effective and can present comparable images must be considered.

There has been very little investigation on the accuracy of colour monitor in the interpretation of radiographs in comparison to a PACS workstation. For the interpretation of CR chest images using colour monitor, particularly PC-based display system, most of the published studies were done by the non radiologists. Two recent studies to involve the radiologists in comparing between colour monitor and PACS workstation concentrated on musculoskeletal system (Doyle *et al*, 2002 and 2005).

To our knowledge, none of the published studies were directly comparable to our study as most of them were of different methodology in term of research setting, monitor display, selection of cases and observers. To date, this is the first study in HUSM to involve PACS, particularly computed radiography, since its implementation in 2000.

The purpose of this study was to compare the diagnostic accuracy and reliability of LCD colour monitor to a high resolution greyscale diagnostic monitor in detection of chest abnormalities on computed radiographs. If diagnosis of images displayed on the relatively low resolution colour monitor, that is ten to twenty times cheaper, is comparable to the high resolution diagnostic greyscale monitor, implementation of hospital-wide PACS might be further justified with possible reduction in cost. In addition, if LCD colour monitor is justified for viewing of projection radiographs, the cost of increasing the number of monitor display would be further alleviated.

SECTION 2:

LITERATURE REVIEW

2.0 LITERATURE REVIEW.

2.1 Picture archiving and communication system (PACS).

PACS consists of image and data acquisition, storage and display subsystems integrated by various digital networks. It can be as simple as a film digitizer connected to a display workstation with a small image data base or as complex as a total hospital image management system. It involves the acquisition of images as digital data, the storage of this digital image data, retrieval and viewing of images on computer monitors, the ability to transmit the digital image data and the archiving of the digital image data (Huang, 1998). The term PACS is used to describe the technologies that are eliminating film which has been the traditional medium for about 80 years (Naul and Sincleair, 2001).

The digitisation of radiology was initiated by a scientist and an engineer trained in electrical and mechanical engineering, Godfrey Hounsfield, who introduced radiologists to the digital world with his invention of CT scan in 1973. He believed that radiography was inefficient and there was a lot to be gained if computers were used in capturing information from x-rays (Rogers, 2001). The term 'digital radiology' was introduced by Dr. Paul Capp in the early 1970s. However, due to lack of technological development, the concept was not popular until the early 1980s. One of the earliest projects related to PACS in the United States was a teleradiology project sponsored by the U.S Army in 1983 (Huang, 1998). Although the concept of PACS has now been in existence for 20 years, advances in computer hardware technology only enabled a realistic clinical entity in the 1990s (Grainger *et al,* 2001).

There are many advantages of introducing PACS technologies to the conventional paper and film-based operation in radiology and medicine. It is possible to manipulate a digital image for value added diagnosis and improve diagnostic value while reducing the radiation exposure to patient. As they promote a more efficient operating environment, PACS can speed up health care delivery and reduce operation cost (Huang, 1998, Grainger *et al*, 2001). The major added value of a PACS is efficiency of data management (Grainger *et al,* 2001). The benefits include cost savings related to decreased use of film, less money spent for processing, storage and handling (Duenrickx and Grant, 1998, Naul and Sincleair, 2001) . Some institutions have found that PACS have led to increased productivity of both technologists and radiologists (Reiner *et al,* 2001, Reiner *et al*, 2002, Redfern *et al*, 2002). Some centers have found that PACS improve the quality of image interpretation and reporting. With large archives of images readily accessible, radiologists more often compare a current study with previous studies (Hayt *et al*, 2001, Hayt and Alexander, 2001). These factors are prompting many institutions to consider moving from a film-based radiology system to PACS (Naul and Sincleair, 2001).

An evaluation of a UK hospital-wide PACS concluded that PACS was almost universally preferred by users and brought many operational and clinical benefits (Weatherburn *et al*, 2003). A hospital wide performance improvement project that was performed in Elmhurst Hospital Center, New York, in 1997, found that physician ordered some x-rays based on habit more than clinical rationale and if they did not receive the results within a specific amount of time a repeat examinations were ordered

(Hayt *et al,* 2001). These factors, together with the many benefits of PACS necessitates an implementation of hospital wide PACS.

Some of the advantages PACS described in literature include the following:

i. No image will be lost or misfiled. This will lead to decreasing the number of missing films. This is a major benefit considering that in many hospitals up to 20% of conventional films are missing (Grainger *et al,* 2001).

ii. Easy comparison with previous examinations or other part of the body.

iii. Easy accessibility of images at all time.

iv. Simultaneous multilocation viewing of the same image on any workstation connected to the PACS network.

v. Faster image retrieval.

vi. Computerised data can easily be duplicated and backed up as precaution against loss and cheaply stored for disaster recovery purposes.

vii. Numerous post processing soft-copy manipulations.

viii. Major reduction in film budget, film packet cost, chemical processing and staff for filing or darkroom technician.

ix. Time saving benefit for the nonradiological clinicians.

Despite many advantages of PACS described above, potential disadvantages should also be considered. PACS is still an expensive technology, even though the costs of hardware and storage media continue to reduce in price. Absolute dependency of a hospital on PACS once it becomes filmless, requires a dedicated maintenance program. This will lead to a requirement for new or retrained personnels specialising in computer engineering or information technology which will also increased the cost.

The capability of PACS to decrease the operating costs of a radiology department has been studied and presented by various authors (Straub and Gur, 1990, Seshadri *et al,* 1994). However, despite substantial research and development of PACS, there are relatively few fully digital PACS installations in clinical use. This is partly due to the financial factors.

PACS was started in Radiology Department, HUSM in 2000. Initial phase of PACS includes CT scan, MRI, fluoroscopy, angiography and ultrasound. Two years later (July 2002) computed radiography (CR) was introduced. Figure 1 summarised the PACS component and architecture in HUSM setting.

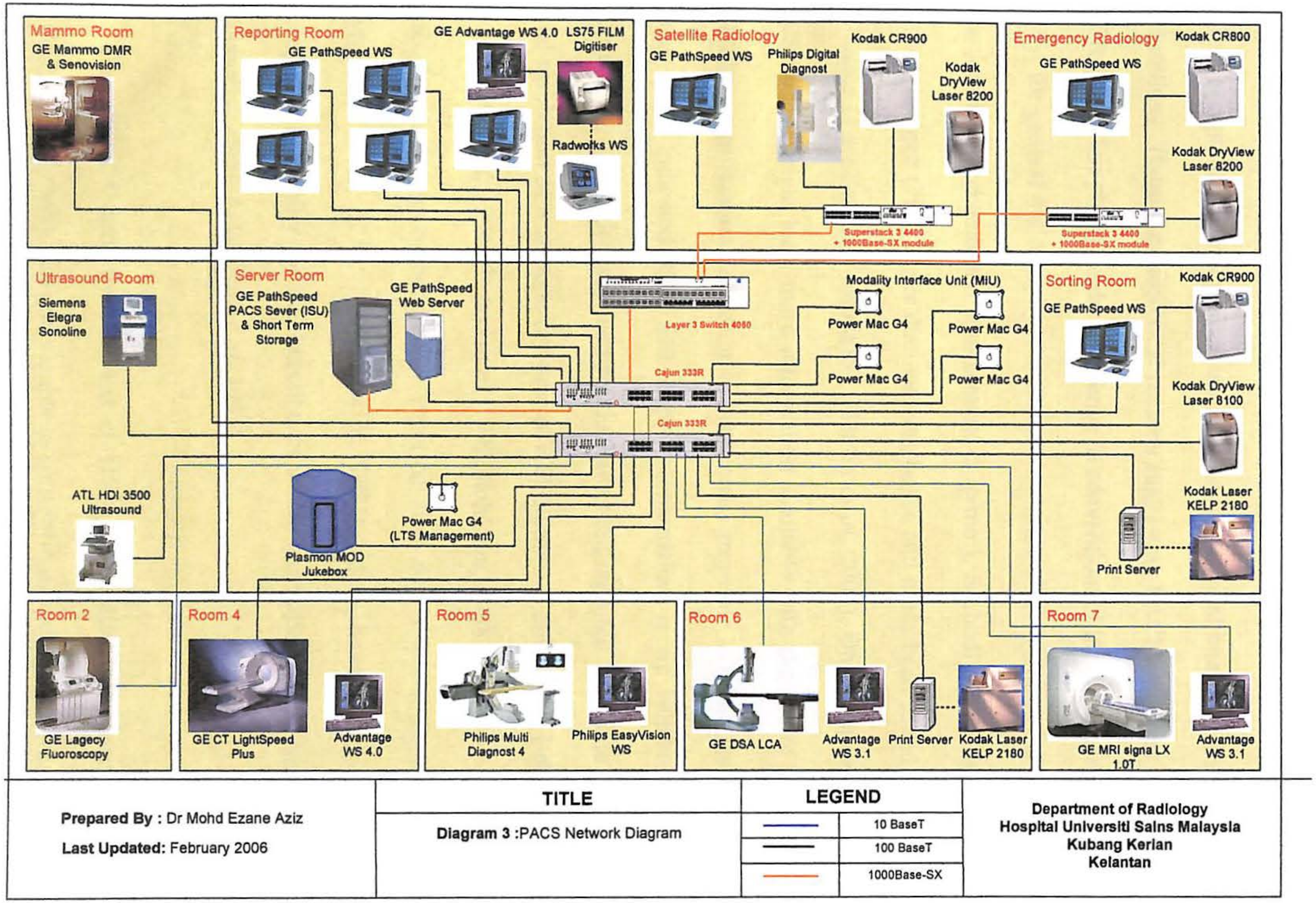

Figure 1: PACS infrastructure and network in Radiology Department, HUSM.

2.1.1 Soft copy versus hard copy.

The most important clinical criterion for use of PACS technology is the ability to achieve acceptable accuracy when interpreting radiological images at a soft-copy viewing workstations. There are theoretical reasons suggesting PACS soft copy images, acquired by CR (phosphor plate) might be inferior to conventional film (Weatherburn *et al*, 2003). Firstly, for general radiography, the spatial resolution of CR (around 2.5 lp/mm) is known to be less than conventional film (around 5 lp/mm). Secondly, the brightness of PACS monitors is three times lower than viewing boxes and it has been found that the effect of luminance is greater than resolution (Herron *et al*, 2000). On the other hand, soft copy PACS images might have more information available with the use of the manipulation tools like magnification, variation in brightness, greyscale window and contrast. Many studies have indicated that soft copy interpretation is as reliable as hard copy interpretation, although discordant results have been reported to be due to differences in spatial resolution of a cathode ray tube (CRT) monitor (Frank *et al*, 1993, Ishigaki *et al*, 1996, Thaete *et al*, 1994, Razavi *et al*, 1992, Itoh *et al*, 1988, Steckel *et al*, 1995, Kundel *et al*, 2001). Some authors have reported that soft copy images are acceptable (Hayrapetian *et al*, 1989, Franken *et al*, 1992), others have found soft copy to be unacceptable especially for the detection of subtle interstitial disease and pneumothorax (Slasky *et al*, 1990, Ackerman *et al*, 1993).

Results of a study by Thaete *et al*, (1994), suggested that observer performance with digital radiography was comparable to conventional radiograph. Razavi *et al*,(1992), in their study on chest radiographs in children, showed no significant difference between viewing images on hard copy and soft copy for detection of pneumothoraces and air bronchograms. A study by Weatherburn *et al*, (2003), concluded that there is no significant difference in detection of chest lesions between conventional film, CR hard copy and PACS soft copy images. Kundel *et al*, (1997), in a prototype study of emergency department radiographs, found that soft copy interpretation was as reliable as hard copy interpretation where the mean kappa was 0.48 for hard copy and 0.49 for soft copy. In a study on accuracy for bedside chest hard copy film versus soft copy CR in medical intensive care unit (ICU), the results gave some justification for using CR chest (Kundel *et al*, 1997). Hard copy and soft copy chest CR images were acceptable for primary interpretation of subtle interstitial lung diseases (Ishigaki *et al*, 1996).

2.1.2 Standard and guidelines.

a) DICOM standard.

DICOM (Digital Image Communication in Medicine) is an internationally recognised standard for PACS and imaging equipment. All modern PACS and imaging equipment conforms to the DICOM standard. ACR (American College of Radiology) and NEMA (National Electrical Manufactures Association) had formed a committee to develop a standard method for transferring images and associated information between devices manufactured by various vendors. This was developed in liaison with other standard organizations. DICOM facilitates interoperability of medical imaging equipment and provides a set of protocols. The standard specified a hardware interface and a minimum set of software commands (http://www.leadtools.com/sdk/medical/ DICOM/ dicomstnd.htm). Refer appendix 2 for parts of DICOM standard. The equipments and tools used in our study conforms to the DICOM standard.

b) American college of Radiology (ACR) technical standard for digital image data management.

The standard includes goals, qualifications of personnel, equipment guidelines, specifications of data manipulation and management, quality control and quality improvement procedures for the use of digital image data resulting in high quality radiological care. These standards are applicable to any system of digital data management. Compliance with the ACR-NEMA DICOM standard is strongly recommended for all new equipments.

For acquisition or digitization, DICOM standard is recommended to be used and the image data set produced should be transferred to the image management system. For small matrix images, each should be digitised to a matrix size as large or larger than the original image on the imaging modality. For large matrix images, digitisation to a matrix corresponding to 2.5 lp/mm or greater in the original detector plane should be made. The system must have annotation capabilities, amount and method of data compression and display of the total number of images acquired in the study.

Display workstations used for official interpretation should be capable of the following:

i. Maximum luminance of at least 50 ft-Lt for greyscale monitors.
ii. Selection of image sequence.
iii. Accurately associating the patient and study demographic with the images of the study performed.
iv. Window and level adjustment
v. Pan and zoom (magnification) functions.
vi. Rotating and flipping the images with preservation of patient's orientation label.
vii. Calculating and displaying accurate linear measurements and pixel value
viii. Displaying prior application of irreversible compression ratio
ix. Displaying the total number of images acquired in the study

The lighting in the reading room must be controlled to eliminate reflections in the monitor.

c) German Radiology Monitor Consensus

The absolute minimal resolution requirements, image orientation and number of displays in a viewing configuration are shown in Table 1.

Table 1 : German Radiology Monitor Consensus

	Colour/ grey scale	*Portrait/Landscape*	*Minimum resolution*	*Number of displays*
CT/MR	Colour Colour	Landscape	1600x1200 CRT 1248x1024 TFT	2
Angio/DSA	Greyscale	Landscape	1600x1200 CRT 1248x1024 TFT	2
Projection Radiology	Greyscale	Portrait/Landscape	1600x1200 CRT with zoom, 2x2.5K CRT	2
	Greyscale		2048x1536TFT	
Thorax	Greyscale	Portrait	2x2.5K CRT	2
Skeletal	Greyscale	Landscape	1600x1200 CRT with zoom, 2x2.5K CRT	2
	Greyscale		2048x1536TFT	

2.2 PACS workstation.

2.2.1 Types of PACS workstation.

a) Diagnostic workstation.

A diagnostic workstation is used by the radiologist for a primary diagnosis of digital images. It is mainly located in the imaging department. This type of workstation has the best quality of image display. If the workstation is used for displaying projection radiographs, multiple 2K monitors are needed. On the other hand, if the workstation is used for CT and MR images, multiple 1K monitors will be sufficient. Table 2 shows some basic software functions required for a display workstation. In addition to the functions shown in Table 2, the diagnostic workstation requires rapid image retrieval (1-2 seconds). Figure 2 shows a two monitor 2K display workstation used in Radiology Department, HUSM.

Table 2: Software functions for a Display Workstation.

Function	Description
Directory	
Patient directory	Name, RN, age, sex, date of current exam.
Study list	Type of exam, anatomical area, date studies taken
Display	
Screen configuration	Reconfigure each screen for the convenience of image display
Monitor selection	Left, right
Display	Display images according to screen configuration and monitor selected
Image manipulation	
Dials	Brightness, contrast, zoom and scroll
LUT	Predefined lookup tables (bone, soft tissue, brain, lung, etc)
Cine	Single or multiple cine on multimonitors for CT and MR images.
Rotation	Rotates an image
Measurement	Linear and region of interest

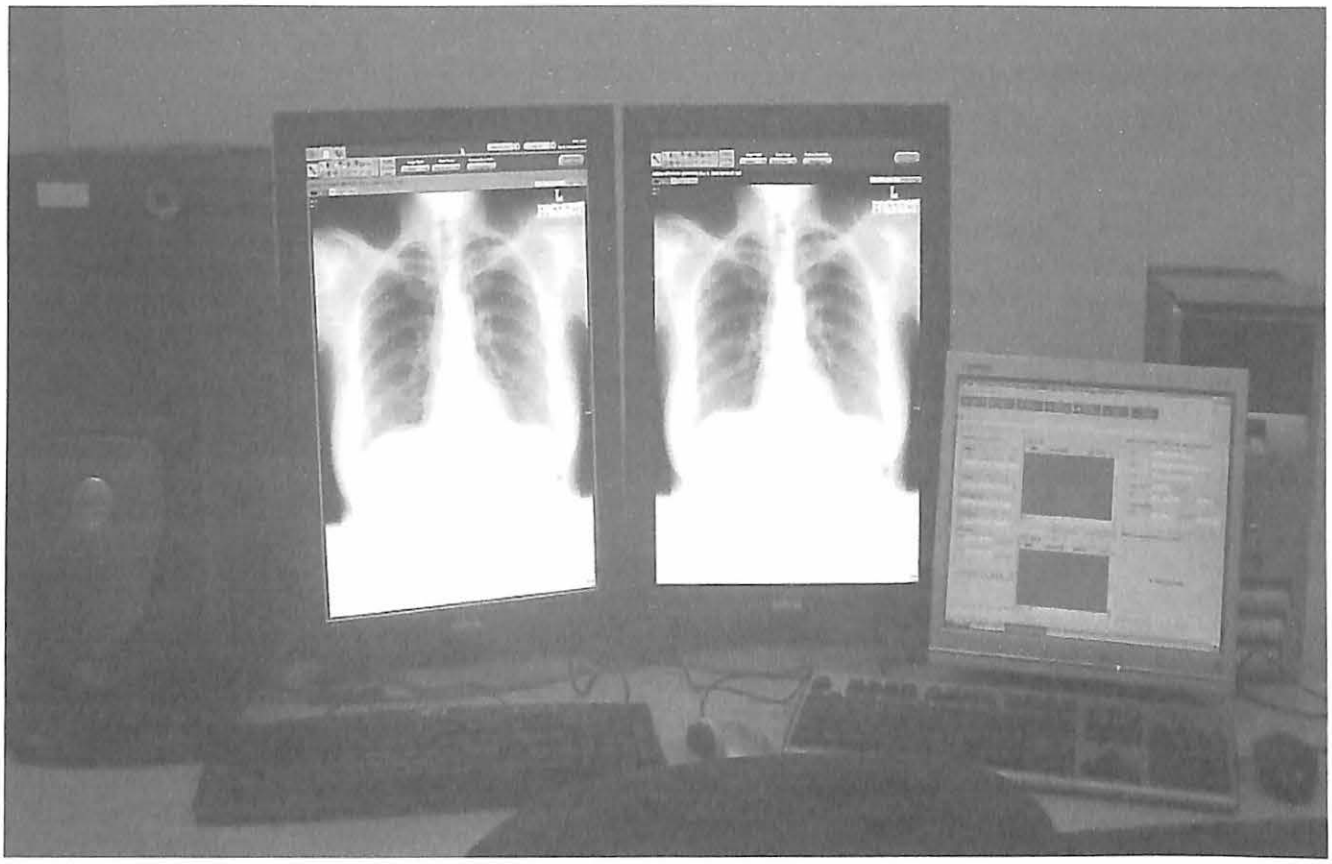

Figure 2: Diagnostic workstation.

b) Review or clinical workstation.

A review workstation is used by the radiologists and referring physicians to review cases. This type of workstation can be located everywhere else in the hospital. It may not require 2K monitors, since images might have been read by the radiologist from the diagnostic workstation and the referring physicians will not be looking for detail. Figure 3, shows a two monitor 1K used for reviewing images in the Radiology Department, HUSM.

c) Analysis workstation.

Analysis workstation is used to extract useful parameters from images. Some parameters like 3-D reconstruction from sequential CT images require analysis workstation with a more powerful image processor and high performance software. Figure 4 shows an analysis workstation displaying 3-D reconstructions of orbit.

Figure 3: Review workstation

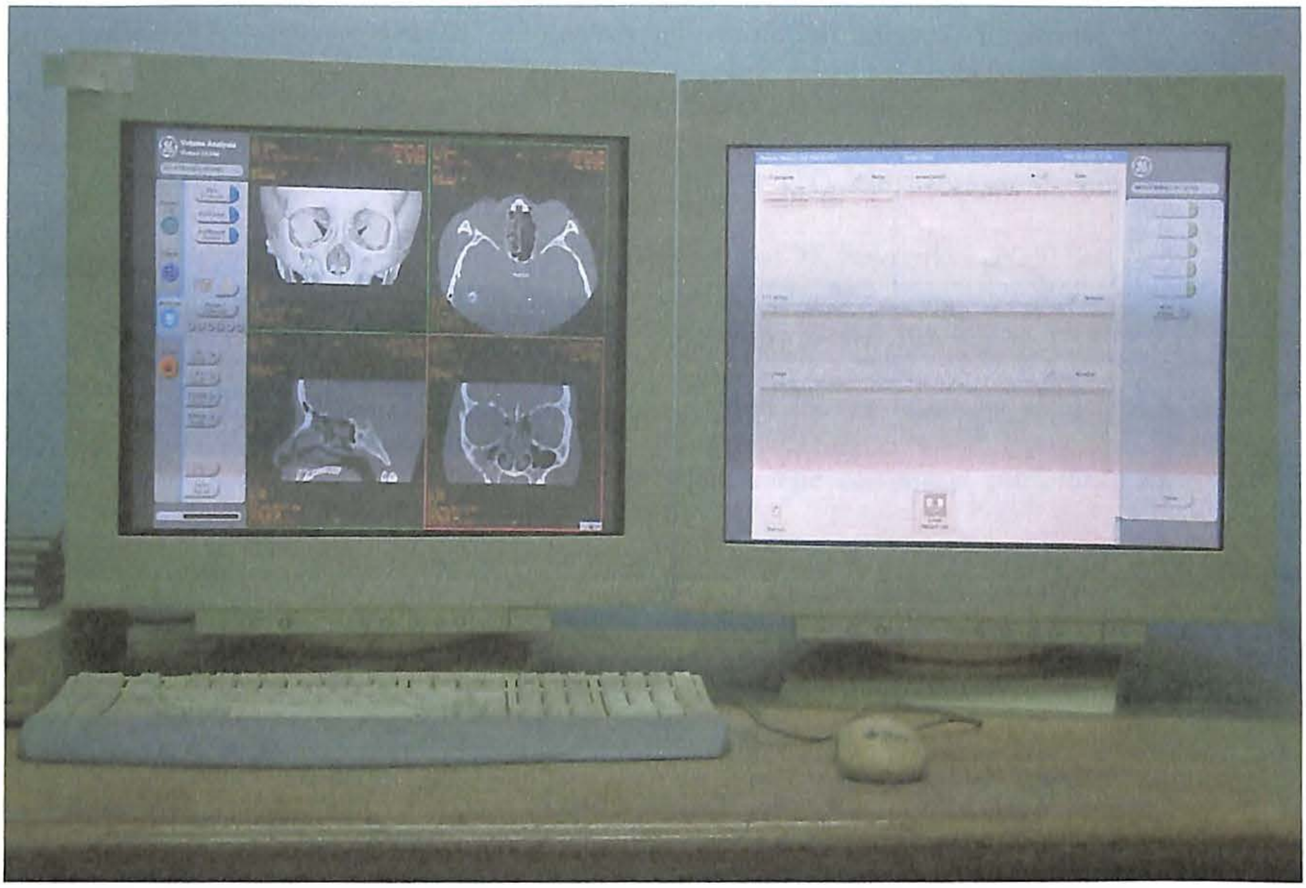

Figure 4: Analysis workstation.

2.2.2 Display monitor.

Quality assurances, contrast, luminance and resolution are very important. The resolution required of a PACS workstation monitor depends upon its use. Monitors of 1K resolution (1000 line or 2 mega pixel) are adequate for CT, MR, ultrasound, nuclear medicine, fluoroscopy and digital angiography. Monitors of 2K resolution (2000 line or 5 mega pixel) are necessary to view plain radiograph images at full resolution. However, 1K monitors with the ability to display the original data at 2K resolution by using a soft copy magnifying tool can be used as a cheaper option. The consensus conference on monitor reporting requires 2K monitors for chest radiography or 1K with zoom and 1K monitors for the other tasks of digital imaging. However, the American College of Radiology (ACR) is recommending 2.5K resolution for primary diagnosis instead of 2K. There are only a few guidelines available for spatial resolution requirement such as The German Radiology Monitor consensus (Table 1) and ACR standard for digital image data management as described in section 2.1.2 Standard and guidelines. The guidelines might be slightly different but they give a good indication about the minimum required resolution for different medical applications.

Contrast is defined as the ratio of black to white. Image quality will be better if the black is darker and the white is brighter. The white is due to the maximum luminance of the monitor. The black is influenced by the technical properties of the monitor and the ambient light. All monitor surfaces reflect ambient light. Smaller ambient light reflection will give better image quality. The brightness (luminance) of PACS monitor is approximately ten times less than conventional viewing boxes. Brighter monitors are better for image viewing but more expensive and burn out phosphors more quickly than lower quality monitors. Black and white (greyscale) monitors are brighter than colour monitors. According to the ACR Standard for Digital Image Data Management, maximum luminance has to be at least 50 ft-Lt (170 cd/m²). Contrast ratio of 100:1 is required for application of class A (primary diagnosis of radiography) and 40:1 for application of class B (primary diagnosis with all other imaging modalities and review). Luminance value of more than 200 cd/m² is necessary when ambient light is taken into account. German consensus conference on monitor reporting, fixed a minimum luminance for digital radiographs of at least 200 cd/m² (Partan *et al,* 2002). With a luminance of 200 cd/m², the dynamic image range of digital images approximates 1:100.

Both theoretical and experimental results have demonstrated that the human visual system is affected by the luminance and contrast of monitors (Herron *et al,* 2000). Only a few comparative studies of monitor luminance have been reported in literature. A reduction in diagnostic efficacy was found with low luminance monitors. A wide range of views concerning spatial resolution for monitors has been presented. For chest radiology, the pixel size should not be larger than 0.2mm, which gives a resolution of 2.5 lp/mm (Otto *et al,* 1998). Ishigaki *et al,* (1996) found that sufficient diagnostic performance can be obtained with 1024 x 1024 monitor. However, in a study by Otto *et al*, (1998), the diagnostic performance with a 1024 x1024 monitor was inferior to that with hard copies. They suggested a higher monitor resolution of 2560 x 2048 with a maximum luminance of 75 ft-Lt to achieve a significant improvement in detecting subtle pulmonary abnormalities. Other study by Herron *et al*, (2000), noted that a resolution of 1024 pixels with monitor brightness of 75 ft-Lt (260 cd/m²) or greater should be sufficient for primary diagnosis with PA chest images. Study on impact of ambient light concluded that catheter detection on soft copy display is significantly decreased by bright ambient light, but it can be compensated with interactive adjustment of window settings (Fuchsjager *et al,* 2003).

a) Cathode ray tube (CRT) versus liquid crystal display (LCD) monitor.

CRT monitor-based reading is currently thought to be as efficient and accurate as conventional film-based reading and is now widely accepted in medical practice (Frank *et al,* 1993, Hwang *et al,* 2003). Most of the studies comparing soft copy and hard copy images used CRT displays and focused on the impact of technical parameters, such as luminescence, spatial resolution and diagnostic performance (Itoh *et al,* 1988, Hayrapetian *et al,* 1989, Cox *et al,* 1990, Slasky *et al,* 1990, Razavi *et al,* 1992, Frank *et al,* 1993, Otto *et al,* 1998, Herron *et al,* 2000, Balassy *et al,* 2005). The CRT monitor is currently being challenged by the LCD monitor. LCDs are common in consumer electronics but only recently have been introduced for soft copy interpretations in radiology (Balassy *et al,* 2005). Compared to CRT displays, LCDs are characterized by a lower matrix size but a higher small-spot contrast ratio and larger dynamic range (Balassy *et al,* 2005). LCD show smaller degradation of display quality with increasing ambient lighting compared to CRT.

Table 3 summarised the most important differences between LCD and CRT monitors.

Table 3 : Differences between LCD and CRT monitors.

LCD	***CRT***
Perfect geometry	Needs geometric correction
Pixelisation due to black lines between pixels	Continuous image
Perfect Modulation Transfer Function (MTF=1)	Imperfect MTF (< 1)
Uniform sharpness	Less uniform sharpness
600:1 contrast ratio (dark reading room)	3000:1 contrast ratio (dark reading room)
Contrast ratio dependent on viewing angle	Contrast ratio independent from viewing angle
LCDs like white	CRTs like black
Imperfect black	Perfect black is possible
Low reflection of ambient light	High reflection of ambient light
Poor stability	Good stability
Poor response speed	Instantaneous response speed
Image retention	No image retention
Blacklight aging	Phosphor aging
Aging independent of image content	Aging is image content dependent
New technology	Mature technology
Low power consumption	High power consumption
No image flicker	Image flicker present

Most recent publications reported no significant difference in observer performance on LCD versus CRT monitor (Langer *et al,* 2004, Balassy *et al,* 2005). Recent study also reported LCD as having excellent spatial resolution, high uniformity and almost complete elimination of veiling glare (Balassy *et al,* 2005). LCD monitor is less bulky than conventional CRT monitor. Since it does not have glass front, they avoid parallax when viewed from the side and is less affected by reflected light (Grainger *et al,* 2001). The most recently introduced active matrix LCD offer some organisational, financial and display advantages compared with the traditional curved surface CRT monitors (Pavlicek *et al,* 2000, Fuchsjager *et al,* 2003). Langer *et al,* (2004), demonstrated no significant change in observer performance sensitivity on 5MP CRT versus 3MP LCD displays for interstitial lung disease. Partan *et al*, (2002), suggested that the most recent developments in monitor technology has made LCD displays suitable for image review and primary diagnosis, both for cross sectional imaging and digital radiography. For detecting small solitary pulmonary nodules, an LCD monitor was comparable to CRT monitor (Hwang *et al*, 2003). A study on observer preference using LCD and CRT for chest radiography, demonstrated an equal visibility under ideal viewing condition (Balassy *et al*, 2005). Even though the LCD based greyscale monitor can be driven at a higher luminance, the colour LCD still has lower luminance compared to CRT monitor. Krupinsky *et al*, (1999), suggested that the luminance of a display system did not significantly influence the final diagnostic conclusion. However, since relatively small amount of studies are available, this conclusion should be used in caution, as different environmental conditions may give different results. One important point from the guidelines available is that for CRT display, the contrast ratio over a wide