



Scintigraphy of the Equine Pelvis

Detectability of equine pelvic lesions: A phantom study

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Uppsala 2004

Report - Master of Science Programme for International Students
Faculty of Veterinary Medicine and Animal Science
Swedish University of Agricultural Sciences
Report no. 38
ISSN 1403-2201

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The present thesis is a partial fulfilment of the requirements for an Master of Science Degree for International Students (MSc) in Veterinary Medicine, at the Swedish University of Agricultural Sciences (SLU), in the field of imaging diagnosis.

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Print: SLU Service/Repro, Uppsala 2004

To my beloved King Rama IX of Thailand
To all my family

Abbreviations used in this thesis

PMTs	Photomultiplier tubes
LEAP collimator	Low energy all purpose collimator
PHA	Pulse height analyzer
LLD	Lower level discriminator
ULD	Upper level discriminator
^{99m} Tc	Technetium-99m
GBq	Gigabecquerel
kBq	Kilobecquerel
ROI	Region of interest
BGR scale	Continuous blue-green-red colour scale

Abstract

Chuthatep, S. 2004. Scintigraphy of the equine pelvis- Detectability of equine pelvic lesions; A phantom study. Master's thesis. ISSN 1403-2201. Report number 38.

Equine skeletal scintigraphy can be used in the diagnosis of pelvic injuries but thick overlying soft tissue is a factor that may decrease the detectability of lesions in this area. The purposes of this study were to examine the effects of soft tissue attenuation on the detectability of lesions and to evaluate the improvement of detectability by using computerized post processing of images.

In this study, an equine pelvic phantom was produced using data from clinically normal horses to simulate the true appearance in a controlled and standardized setup. In an observational study, 11 observers evaluated scintigrams to find out the maximum depth of overlying soft tissue at which a lesion could be distinguished. Scintigrams with varying lesion contrasts, count levels, filtered and unfiltered and in two different colour displays were produced to evaluate factors influencing the detectability.

The result showed that lesions with 130 percent contrast and less were obscured by overlying tissue that was 9 cm or more thick. Increasing the count level from 300 kcounts to 500 kcounts did not improve the lesion detectability. A Metz digital filter increased detectability of the lesion with 120 percent contrast of 50 and 150 kcounts scintigrams.

Colour displays did not influence lesion detectability. The combination of an equine pelvic phantom and an observational study can be used to evaluate factors influencing the detectability in scintigrams. The results in this study show that less intense increase radiopharmaceutical uptake may be difficult to detect due to attenuation of thick overlying soft tissue.

Key words; equine pelvis, phantom, soft tissue attenuation, detectability

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Contents

General Background, 9

Introduction, 9

Anatomy of the equine pelvis in diagnostic imaging, 11

Radiography of the equine pelvis, 11

Ultrasonography of the equine pelvis, 11

Scintigraphy of the equine pelvis, 12

Skeletal scintigraphy, 13

Gamma camera, 13

Collimator, 14

Scintillation detector, 15

Positional circuit, 16

Pulse height analyzer, 16

Scalers, 17

Analog-to-digital converter, 17

Radiopharmaceutical, 17

Image acquisition, 17

Matrix size, 18

Time and count acquisition, 18

Image processing, 18

Digital filter, 18

Colour display, 19

Motion correction, 19

Image interpretation, 19

References, 20

Introduction to the Research Report, 22

Aims of the Research Report, 23

Research Report, 24

Detectability of equine pelvic lesions; A phantom study

Suwicha Chuthatep, Mieth Berger, Per Eksell

Acknowledgments, 33

General Background

Introduction

Usually, pelvic injury or pelvic fracture is caused by severe trauma and presents with moderate to severe unilateral hind limb lameness as the most common clinical sign. In addition, severe pain and soft tissue swelling may be present (Little and Hilbert, 1987; Rutkowski and Richardson, 1989).

Fractures of the pelvis occur most frequently in the ilium especially on the ilial wing (Jeffcott, 1982; Pilsworth et al., 1994; Hendrickson, 2002). The fracture site has no significant relationship with age, sex, degree of lameness or the long term outcome (Rutkowski and Richardson, 1989). In cases with incomplete fracture, early detection will enable an early decision thereby decreasing pain and avoiding catastrophic injuries (Pilsworth et al., 1994). Thus early and correct diagnosis is important. Physical, radiographic, ultrasonographic and scintigraphic examinations are used to diagnose pelvic fractures. The physical examination may include a rectal or vaginal palpation, checking for external crepitation or anatomical abnormal changes of the pelvic area. In horses with an ilial fracture, the lesion is covered by thick gluteal muscle that may make the fractured area very difficult to examine. Muscle atrophy may be present if the duration of the fracture is more than 2 weeks (Little and Hilbert, 1987) and in some cases a large hematoma may be palpable more acutely (Hendrickson, 2002). Crepitation has been found to be an unreliable sign (Little and Hilbert, 1987). Physical examination is not specific or sensitive enough to fully evaluate a pelvic injury in most cases, and special methods are necessary.

The radiographic examination is a widespread and useful method that may detect a displaced fracture of the pelvis. Radiography of this area is best performed under general anesthesia but a major problem is the risk of causing a more complete fracture and displacement when the horse is recovering from anaesthesia (Hendrickson, 2002). High exposures are required and scattered radiation from the large amount of soft tissue in the region should be considered (Butler et al., 2000).

Ultrasonography can be very helpful in the evaluation of the musculoskeletal system of the pelvic area in the standing horse. Unfortunately, there are also some limitations for its use. A fracture with minimal displacement or poorly developed callus will be difficult to evaluate. The thick muscle mass lying on top of the bone requires a deeply penetrating transducer. In horses with large amounts of subcutaneous fat or numerous blood vessels running through the musculature, achieving an optimal angle to the fracture may be difficult (Shepherd and Pilsworth, 1994). If severe pain is present in the fracture area, the horse may move away from the probe making the examination more difficult. The relatively small field of view in ultrasonography may give detailed information but overview of larger areas takes a long time, which the horse may not allow. Also, ultrasonography normally requires a highly skilled examiner.

Skeletal scintigraphy is an imaging method based on detection of the distribution of gamma rays by a gamma camera after injection of a bone seeking

radiopharmaceutical. Scintigraphy has been claimed to be the most sensitive and useful diagnostic technique for the detection of fractures in the equine pelvis (Steckel, 1991; Pilsworth et al., 1994; Hornof et al., 1996; Hendrickson, 2002). Increased radiotracer uptake is caused by increase in blood flow and/or osteoblastic activity, which are features of healing fractures (Smith, 1989). Scintigraphy can be used in the standing horse and relatively large areas are examined in each scintigram which makes the examination quite rapid. The scintigraphic anatomy of the equine pelvis has been studied by (Erichsen et al., 2002) and one conclusion was that the soft tissue can decrease the accuracy of pelvic injury diagnosis, since thick gluteal muscles will attenuate a large portion of the gamma rays from the pelvic bone. The effect of soft tissue attenuation has also been described in two clinical cases with pelvic bone injury in which gluteal muscle atrophy produced a false asymmetric uptake of radionuclide in the pelvis (Erichsen and Berger, 2000). The soft tissue attenuation on the appearance of the normal equine pelvic scintigram has a dramatic effect on the appearance and counts. The pixel count was up to 6 times higher on the side of the pelvis from which the soft tissue covering the pelvis was removed than on the contralateral side (Erichsen et al., 2000). It has been suggested that the attenuation would make only severe bony lesions detectable (Erichsen et al., 2003).

Smith (1987) has described that in human bone scintigraphy a 20% change in uptake can be appreciated visually. In an observational study of simulated lesions in true equine tarsal scintigrams, a majority of the lesions with a 15% increase was detected (Eksell et al., 2000a;b). These were in areas with no overlying soft tissue.

Some improvement of image detectability may be obtained by digital filtering or by changing colour display. A digital filter removes some of the unwanted information in the image and various colour displays enhances the perceived contrast between regions of different intensity. The effects of a digital filter and color display on detectability of a lesion were evaluated in an observational study of created lesions in true equine tarsal scintigrams. The result showed improved detectability of the lesion by using Metz filter and continuous Blue-green-red display in low counts scintigrams compared to unfiltered images and continuous greyscale display (Eksell et al., 2000a;b).

Motion of the horse during acquisition will degrade the resolution in the scintigrams. In the clinical situation, a motion correction program can be used to compensate for the effect of motion (Lord et al., 1998). However the effect of overlying soft tissue on the detectability of a lesion and the effects of a digital filter and different colour displays in scintigrams with overlying soft tissue in the horse have not been studied.

Anatomy of the equine pelvis in diagnostic imaging

The pelvic girdle consists of the sacrum, the first three caudal vertebrae and both sides of os coxae made up by ilium, ischium and pubis. In the immature horse, separate sites of ossification occur in the iliac crest and the tuber coxae. The ilium area is covered by the large muscle mass of the gluteal medius especially on the dorsolateral surface (Riegel and Hakola, 1996). Fractures of the ilial wing usually extend obliquely in a craniocaudal direction. The fracture is often displaced by pull of the muscle mass which attach to the tuber coxae. Large fissures may extend towards and sometimes involve the sacroiliac joint (Butler et al., 2000).

Radiography of the equine pelvis

For accurate equine pelvic radiography, it is important to position the horse in a strict dorsal recumbency (figure 1a, 1b). For complete radiographic assessment of the pelvis in an adult horse, seven standard overlapping radiographic views are recommended (Butler et al., 2000).

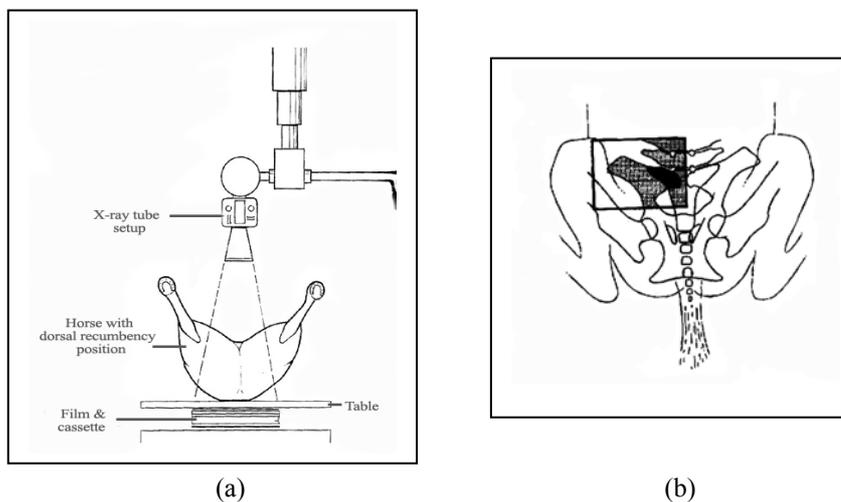


Figure 1. Position of the x-ray machine, horse and cassette to obtain ventrodorsal radiographic views of the pelvis (a). The cassette position for the iliac wing (b).

Ultrasonography of the equine pelvis

The normal ultrasonographic appearance of the ilium wing is a smooth and regular concave hyperechoic line extending between the tuber sacrale and tuber coxae (figure 2a). Acoustic shadowing and refraction artifacts can be created by the many blood vessels in the musculature. The ilial wing fracture may appear as a disruption or fracture gap in the ilial wing contour (Shepherd and Pilsworth, 1994).

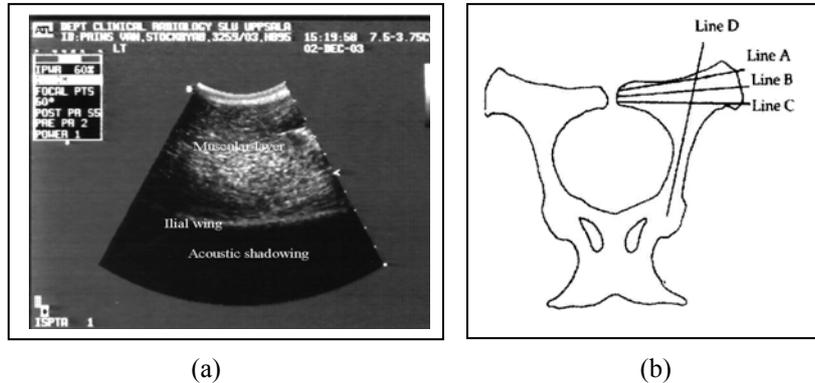


Figure 2. Ultrasonogram of a normal ilial wing (a). Schematic diagram of the pelvic showing reference lines used to examine the ilial wing (line A, B and C) and ilial shaft (line D) (b) (Shepherd and Pilsworth, 1994).

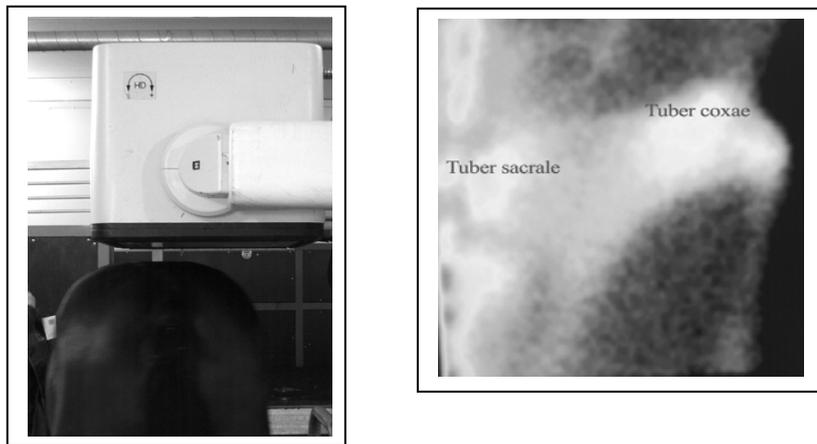
Scintigraphy of the equine pelvis

In scintigraphic examination of the equine pelvis, there are two important landmarks used, the tuber coxae and the tuber sacrale. It is necessary to know the anatomy of these important landmarks on the scintigram. In the lateral view, the tuber coxae is the prominent landmark (figure 3a). In the dorsal view, the tuber coxae form the cranio-lateral landmark of the pelvis and the tuber sacrale is the medial landmark that is located lateral to the sacral spine (figure 3b).

Routinely, scintigraphy of the equine pelvis includes both lateral (collimator face perpendicular to the ground) and dorsal views (collimator face parallel to the ground) (figure 3a, 3b). In addition, the oblique view has been reported to show fractures of the ilium more clearly than other views since the ilium in this view is positioned more parallel to the camera face and the effect of soft tissue is diminished (Hornof et al., 1996).



(a)



(b)

Figure 3. Standard views in equine pelvic scintigraphy. Lateral view, collimator face perpendicular to the ground and the normal scintigram (a). Dorsal view, collimator face parallel to the ground and the normal scintigram (b).

Skeletal scintigraphy

Gamma camera

The gamma camera is the detector for imaging in nuclear medicine. The gamma camera compounds are a collimator, scintillation crystal (NaI(Tl) crystal), photomultiplier tubes (PMTs), positional circuit, pulse height analyzer, and recording device. (Figure 4)

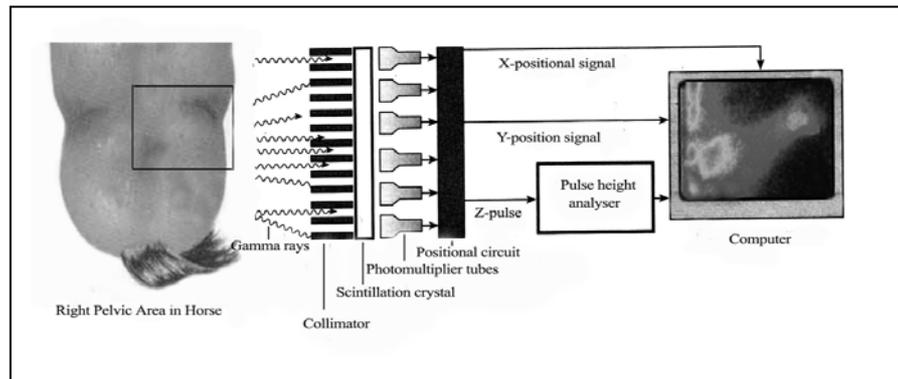


Figure 4. The basic components of a gamma camera. (Illustration modified from (Twardock, 2003) in Dyson et al, 2003, Equine Scintigraphy)

Collimator

Collimators are used to prevent gamma rays that are not perpendicular to the collimator opening from reaching the detector assembly. The collimator selection will affect the image size, spatial resolution and sensitivity of the camera system. The most common type, the parallel-hole collimator consists of a lead plate through which runs a series of small holes whose axes are perpendicular to the face of the collimator and parallel to each other. The parallel holes of the collimator vary in diameter and height depending on the purpose of the collimator.

The two principal parameters describing the collimator performance are sensitivity and spatial resolution. The sensitivity is the ratio between gamma rays emitted by the patient and detected gamma rays. Resolution is measured as the minimum distance needed to separate two structures from each other. Typically, the resolution of a parallel hole collimator is about 7 mm (Sharp, 1989). The three common types of parallel hole collimators include; 1.low energy all (or general) purpose (LEAP) collimator, 2.high resolution collimator and 3.high sensitivity collimator (Figure 5). In equine scintigraphy, a parallel hole with LEAP collimator is a good compromise between image quality (mid-range resolution and sensitivity) and acquisition time.

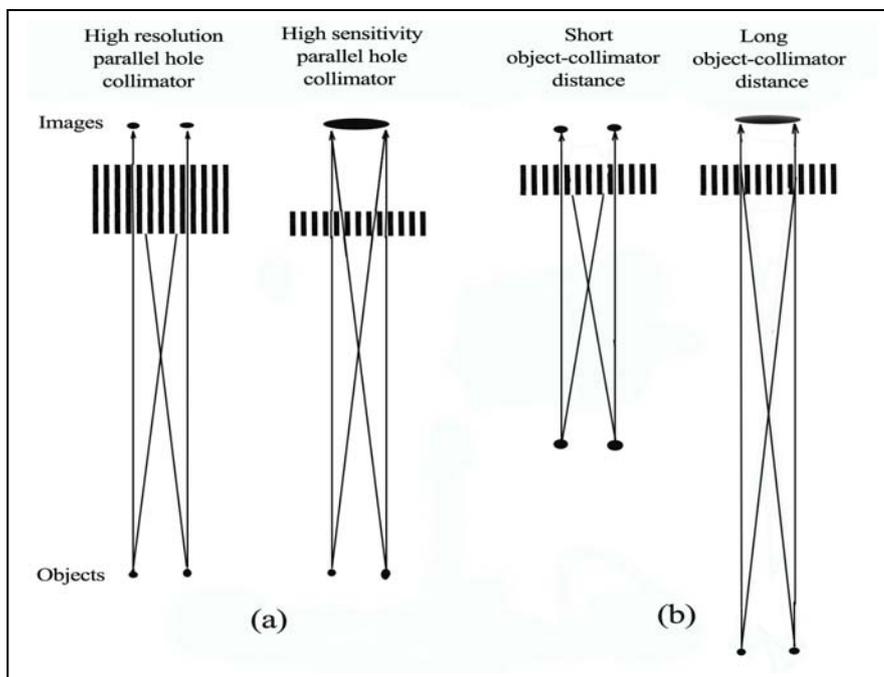


Figure 5. The effect of different collimators and different object-collimator distances on scintigraphic images. Comparison between a high resolution parallel hole collimator and a high sensitivity parallel hole collimator. The high sensitivity one lets more photons pass, but cannot resolve the two points (a). Comparison between short and long object-collimator distances. Short distance improves the resolution compared to long distance (b).

The parallel hole collimators are also subdivided into specific energy ranges for the different energy of radionuclides used including a low energy (< 140 keV), a medium-energy (< 260 keV) and a high-energy (< 400 keV) collimator (Sharp, 1989). The low energy collimator is preferred primarily for the 140 keV photon of ^{99m}Tc which is the radionuclide used in equine skeletal scintigraphy and in this study.

The distance between object and collimator will affect the angle of gamma rays hitting the collimator (Figure 5). Increasing this distance will increase the proportion of the gamma rays passing the collimator but will decrease the resolution of the scintigram. On the other hand, increasing the distance will decrease the number of the detected gamma rays as a result of the inverse square law.

Scintillation Detector

The scintillation detector functions both as a counter and a position detecting device. This process takes place in two stages. The first step is the conversion of the absorbed gamma-rays into visible light by scintillation, using a thallium activated sodium iodide (NaI(Tl)) crystal. In the second step, these visible light signals are converted into electrical signals by the photomultiplier tubes (PMTs).

The PMTs are usually arranged in a closely-packed hexagonal array to ensure that the smallest possible gaps are left between tubes. Typically the number of tubes in gamma cameras is 37, 61, or 91 depending upon the size of the photocathodes and diameter of the crystal.

Positional Circuit

The camera's positioning circuit will determine the position of each gamma ray absorbed in the scintillation detector. The address of the gamma ray is located by vertical and horizontal positions received from the calculated output signal values after passing through PMTs. The output signal values from the positional circuit are then summed and used to determine the electric signal (Z-pulse or Z-signal) in the pulse height analyzer (see below). Thus, a large number of PMTs in a gamma camera will improve the ability of the positioning circuitry to determine the address of the gamma rays absorbed in the scintillation crystal and thus improve resolution.

Pulse Height Analyzer

Some of the electrical signals (Z-signal) that have passed through from positional circuit are caused by scatter and will not carry useful information. All signals are received by the pulse height analyzer (PHA) which is an energy discriminator that limits the recorded signal to a specific amplitude signal range that is called the energy window (figure 6). The signals with an energy above or below the set energy window will be rejected. The window is adjusted so that the center of the window is on the photopeak of the radionuclide used. Typically a window width equal to 20% of the peak energy value is used. For ^{99m}Tc photopeak energy is 140 keV, a 20% window would be 28 (± 14) channels wide. Corresponding, the lower level discriminator (LLD) and upper level discriminator (ULD) would be 126 keV and 154 keV respectively. A wide energy window would increase count rate but also increase noise by detecting scatter radiation.

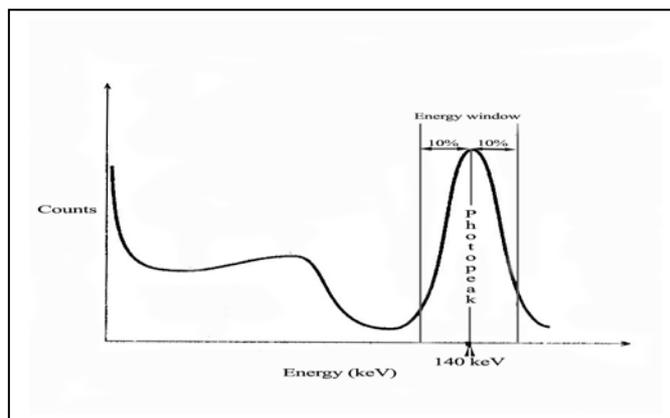


Figure 6. The energy window typically set at $\pm 10\%$ of the photopeak of ^{99m}Tc .

Scalers

The scaler or counter counts the gamma rays accepted by the pulse height analyzer. This count information is used by the camera to define each image. Image acquisition will be either time based or count based.

Analog-to-Digital Converter

The output signals of the gamma camera consists of three analog signals; x, y, and z. The x and y signals give the positional information for each event and the z signal is the energy information. These signals will pass through an analog-to-digital converter to be converted into discrete electrical information. Finally, this information contained in the digital image can be displayed, stored and manipulated in a computer.

Radiopharmaceutical

Technetium-99m (^{99m}Tc) is the radionuclide used in equine skeletal scintigraphy (Lamb and Koblik, 1988; Lamb and O'Callaghan, 1996; Driver, 2003). ^{99m}Tc emits gamma rays of 140 keV with a physical half life of 6 hours. The ^{99m}Tc is chemically bound to a diphosphonate such as methylene diphosphonate (MDP) or disodium oxidronate (HDP) to form a bone seeking radiopharmaceutical. The dosage of ^{99m}Tc -MDP used in horses is 3.7 to 5.1 Gigabecquerel (GBq) for 500 kg administered intravenously (Lamb and O'Callaghan, 1996). After injection, the examination can be divided into three phases. Phase 1 is the vascular phase, when the radiopharmaceutical is still predominantly in large vessels. In phase 2 or soft tissue phase, the radiopharmaceutical is distributed in the capillary bed and extracellular fluid. In the phase 3 or the bone phase, ^{99m}Tc diphosphonate binds to the exposed surface of the hydroxyapatite crystals in bone. All skeletal scans use phase 3 and the other phases are used occasionally to evaluate the soft tissue. Taking radionuclide decay into account, optimal contrast between soft tissue and bone of phase 3 occurs 2-4 hours after injection (Lamb and Koblik, 1988; Lamb and O'Callaghan, 1996; Driver, 2003). In this study, sodium ^{99m}Tc pertechnetate was used to produce all phantom images and biodistribution was not a factor.

Image acquisition

Image acquisition parameters must be set prior to a scintigraphic examination. These parameters will effect the image quality and different settings are used in different situations. The scintigraphic study can be acquired as dynamic or static. The dynamic study is an acquisition of a preset series of image frames used to evaluate the uptake and/or clearance of the radiopharmaceutical over time to obtain functional or kinetic information. The static study is the single frame study used to evaluate the intensity of the radionuclide distribution by an image of the uptake in the bone. To obtain sufficient detail the static acquisition time needs to be 30-120 seconds, depending on the area examined.

Matrix size

Matrix size is the number of pixels used to acquire the image and in each pixel the number of gamma rays detected will represent the corresponding location on the camera face. Thus, a large matrix size will result in small pixel size which may enable high spatial resolution of the image. However, scintigraphic examinations will normally not require large matrix size since the resolution of the gamma camera with a LEAP collimator is about 7 mm. Using a large matrix with a pixel size smaller than the best resolution of the gamma camera system cannot improve image quality. Large matrix size and more pixels results in reduced pixel count which may require prolonged acquisition times and increase the risk of motion blurring (Driver, 2003).

Time and Count acquisition

Acquisition can be set by time or counts which means that the acquisition ends after a preset time or when a preset number of counts is registered. Acquisition by time enables the direct comparison of contralateral images provided that the view is identical. Acquisition by count ensures a similar image quality of the same regions examined (Driver, 2003). Normally, for skeletal scintigram in horses 75 to 300 kcounts are required (Lamb and Koblik, 1988; Chambers, 1996; Dyson and Martinelli, 2003), again depending on the examined area.

Image processing

Digital filtering

The image quality is an important factor for accurate evaluation of scintigrams and image noise may decrease the image quality and prevent detection of present lesions. Image noise can be explained as the variation in pixel count in an area which ideally is uniform. The best approach to reducing image noise is to collect more signal or counts (Russ, 1995) but this is sometimes difficult in clinical equine scintigraphy because of the long examination time. Interaction between gamma rays from the bone and overlying soft tissue will cause scatter also contributing to noise in scintigrams of the pelvis (Erichsen, 2003). More overlying soft tissues will cause more scatter. Digital filtering might be an alternative to raising the number of counts in the image (Starck, 1997; Eksell et al., 2000b). The digital filter is an effective technique in computer analysis of scintigrams that has been used to reduce image noise (Miller and Sampathkumaran, 1982; Hornof, 1996). The Metz filter has been suggested to be the best digital filter in term of improving both sensitivity and specificity in simulated images of the thoracolumbar region in humans (Starck and Carlsson, 1997). In equine scintigraphy, a Metz filter improved lesion detectability in many count levels especially in low count scintigrams (50 kcounts) in phantoms simulating the equine tarsal bone, with slight loss of specificity (Eksell et al., 2000b). The use of a Metz filter has been recommended to allow a decrease in acquisition time or a decrease in the administrated dose of radioactivity (Starck and Carlsson, 1997; Eksell et al., 2000b). Horses with pelvic injury may be painful and have

difficulties to stand still during image acquisition. Decreasing the acquisition time would be of great value to reduce motion blur which is not always completely corrected by the motion correction program, and this program is not supplied by all software vendors.

Colour display

The display of digital images results from a colour or level of grey being assigned a specific value. The continuous grey scale display is often used and has been suggested to minimize the risk of overinterpretation (Weekes and Dyson, 2003). Although the colour scale display has been claimed to produce false positive results in digital images (Hornof, 1996; Weekes and Dyson, 2003), several studies have found colour display to be superior (Goin et al., 1983; Crowe et al., 1988; Eksell et al., 2000a). In equine skeletal scintigraphy, Eksell (2000b) reported that colour displays, especially continuous blue-green-red display scale, improve detectability of a simulated bone lesion. The effect of colour displays on the detectability of lesions in the equine pelvis has not been evaluated.

Motion correction

Image blurring is caused by the movement of the examined region during acquisition. In equine scintigraphy, regions proximal to the fetlock will move during acquisition (Weekes and Dyson, 2003). Post processing of images obtained by dynamic acquisition using a motion correction program improved the image resolution in equine scintigraphy and the best resolution images were produced at the acquisition time equal 1 frame per second (Lord et al., 1998).

Image interpretation

Fractures will normally cause an increase in blood flow and an increase in osteoblastic activity. These metabolic bone responses result in increased radiopharmaceutical uptake (Smith, 1989; Chambers, 1996; Dyson and Martinelli, 2003). The local uptake ratio such as lesion/bone ratios are the simplest method to quantify the uptake of radiopharmaceutical in an area of injured bone (Smith, 1987). Several studies in human bone scintigraphy reported that changes in uptake of 20% can be detected (Matin, 1987; Smith, 1987). The evaluation of an equine scintigram is reported in terms of size, pattern of distribution and intensity. The distribution of uptake can be classified as focal, local or diffuse. The intensity of uptake is expressed as mild, moderate or severe (Chambers, 1996). The interpretation of equine scintigrams is subjective and not standardized. It largely depends on the experience and skill of the interpreter.

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Introduction to the Research Report

Making images of the equine body in order to diagnose illness is not always uncomplicated. A major problem in skeletal diagnostic imaging is the large amounts of overlying soft tissue in some areas. The effects of thick overlying soft tissue in skeletal scintigraphy are not fully known and knowledge about these effects would be invaluable for correct evaluation of clinical cases. Computerized post processing of digital images has been reported to improve detectability of lesions in skeletal scintigraphy but has not been tested in skeletal scintigrams with thick overlying soft tissue specifically.

Aims of the Research Report

The purposes of this study were to examine the influence of the thickness of overlying soft tissue on the detectability of a linear lesion by using a scintigraphic phantom simulating a part of the equine pelvic area. A second purpose was to evaluate the effects of different colour scales and distal filtering of the images on the detectability of the lesion.

Research Report

Detectability of equine pelvic lesions; A phantom study

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Introduction

Pelvic fractures have been reported to cause lameness in horses (Little and Hilbert, 1987; Rutkowski and Richardson, 1989). The most common clinical sign is unilateral hind limb lameness (Little and Hilbert, 1987; Hendrickson, 2002). Usually, the fracture is located in the wing of the ilium (Jeffcott, 1982; Little and Hilbert, 1987; Riegel and Hakola, 1996; Hendrickson, 2002). (Haussler and Stover, 1996) found all stress fractures were located to the ilial wing. The wing and shaft of ilium are covered by thick muscle, the gluteal medius, which makes the physical examination more difficult (Little and Hilbert, 1987).

Several diagnostic modalities are used to evaluate pelvic injuries in horses. In radiography, it is important to position the horse in strict dorsal recumbency under general anaesthesia to produce optimal radiographs (Butler et al., 2000; Hendrickson, 2002). But general anaesthesia increases the risk of exacerbating a pelvic fracture (Hendrickson, 2002).

Ultrasonography can be useful in the diagnosis of equine pelvic injuries (Pilsworth et al., 1994; Shepherd and Pilsworth, 1994). Unfortunately, only displaced fractures can be seen and many are not displaced.

Skeletal scintigraphy is claimed to be the best diagnostic technique for the detection of stress fractures in the equine pelvis (Hendrickson, 2002). Several studies have reported that overlying soft tissue obscures lesions in the equine pelvis (Erichsen and Berger, 2000; Erichsen et al., 2000; Erichsen et al., 2002; Erichsen et al., 2003). The amount of this obscuring effect is unknown. Also, blurring of the image from movement of the examined horse will decrease image quality. A motion correction program can minimize this problem (Lord et al., 1998). Improvement of the detectability of a lesion by using digital filtering and different colour displays in equine scintigrams has been reported (Eksell et al., 2000a;b).

The purposes of this study were to examine the effect of overlying soft tissue on the detectability of a linear lesion and to evaluate possible effects of digital filtering and different colour displays by using a phantom model.

Materials and Methods

Phantom model preparation

The intensity of radiotracer uptake relationship between soft tissue and an active part of the pelvis in a dorsal view of the pelvis was determined by using regions of interest (ROIs) in 15 clinically normal horses. One region of interest (ROI) was drawn just medial to the tuber coxae (ROI 1) and another on the soft tissue area caudal to the tuber coxae (ROI 2) (Figure 1a, 1b). All ROIs were 200 ± 10 pixels large. The average ROI ratio (ROI 1/ROI 2) was calculated and the result was used to simulate an authentic appearance with the phantom model.

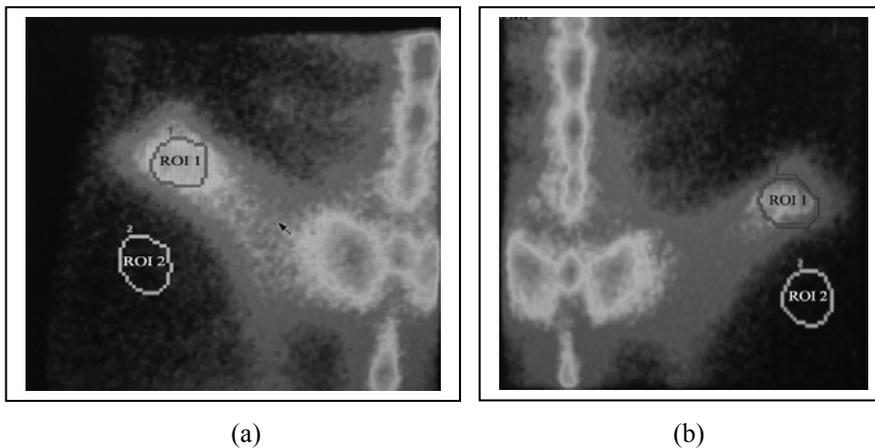


Figure 1. ROIs placed just medial to the tuber coxae (ROI 1) and in the gluteal area (ROI 2) were used to measure the intensity relationship between soft tissue and bone. Left dorsal view (a), Right dorsal view (b).

A phantom was made from plexiglass and consisted of three cases: a large case (case A), a smaller case (case B) and a plastic tube (case C). Case A was wedge shaped 2 to 12.5 cm deep, 25 cm wide and 45 cm long. Case B was parallelogram shaped 2 cm deep, 15 cm wide and 45 cm long. Case C was a plastic tube 45 cm long, with an inner diameter of 4 mm (Figure 2a, 2b).

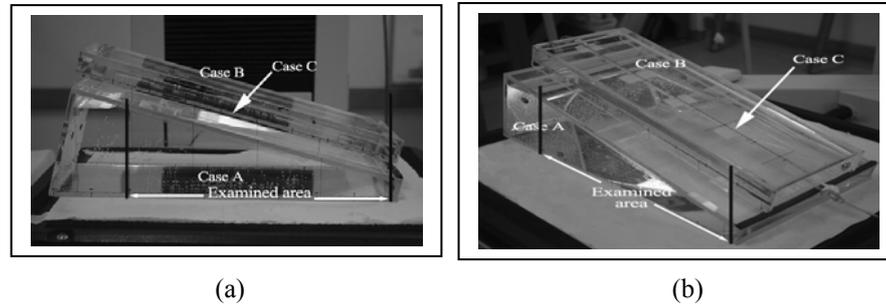


Figure 2. Phantom setup used in this study. View from side (a), Oblique view (b).

The three cases of the phantom were filled with water containing different concentrations of Technetium-99m (^{99m}Tc) solution. Case A was filled with 7700 ml of ^{99m}Tc solution with a concentration of 2.5 kBq/ml to simulate the gluteal muscle. Case B was filled with 1300 ml of ^{99m}Tc solution with a concentration of 50 kBq/ml to simulate the pelvic bone. Case C was filled with 5.5 ml of ^{99m}Tc solution with 74, 166, 259, 351 and 444 kBq/ml to produce 110, 120, 130, 140 and 150 percent uptake respectively in relation to case B to simulate linear lesions with different intensities. In the negative controls, Case C (the plastic tube) was not filled at all.

The different concentrations of ^{99m}Tc solution were produced by using a Gamma-counter (CRC[®]-15R Capintec, Scanflex Medical AB, Sweden) and a digital scale (PB 303 DeltaRange[®], Mettler Toledo, Switzerland)

Image acquisition

The scintigraphic images were obtained using dynamic acquisition with the phantom placed directly on top of the gamma camera (Figure 2a, 2b). A square field of view gamma camera, equipped with 61 photomultiplier tubes and a low energy general-purpose collimator (Picker SX-300. Picker Corp., Ohio, USA.) were used. A dedicated nuclear medicine software (HERMES, Nuclear Diagnostics, Stockholm, Sweden) was used for acquisition and post processing. Images were acquired in a 128*128 matrix at 50 kcounts/ frame for 10 frames. The negative controls were acquired first and 110, 120, 130, 140 and 150 percent lesions followed in that order, to avoid contamination of the tube with the more concentrated radioactive solutions.

Image processing

Static images with 50, 150, 300 and 500 kcounts were produced by adding frames. Each image was duplicated in two colour displays, continuous grey scale display and continuous blue-green-red display. The images were duplicated and the duplicated set was filtered with a Metz filter. The setting of the Metz filter was

optimized using the result from frequency analysis of the images with different count statistics.

Table 1. *The complete set of scintigrams included in the study.*

Variable	Alternatives	Images with lesion (n)	Images without lesion (n)
Image counts (kcount per image)	50, 150, 300, 500	4	4
Lesion contrasts (% of background)	100, 110, 120, 130, 140, 150	5	2*
Display mode	BGR scale, Grey scale	2	2
Digital filters	Yes (Metz filter) No (RAW)	2	2
Total		80	32

* = Scintigrams without lesion (negative control) were duplicated.

BGR scale = Continuous blue-green-red colour scale

Images analysis

A group of 11 blinded observers comprised 9 radiologists and 2 scintigraphic technicians. Five of the radiologists were highly experienced in evaluating scintigrams. The images were randomized and evaluated under identical conditions. Before the evaluation, all observers together were informed about the construction and setup of the phantom. At the evaluation, the observers were asked to decide if a linear lesion was present. If a lesion was considered present, the length of the lesion was determined by the observer and measured by the same research leader (Chuthatep), using the dedicated software. All scintigrams were shown and evaluated on the same computer monitor (UltraSharp model, DELL™, Korea). All results were recalculated into depth using a formula derived from the shape of case A as a straight line equation ($y = \text{slope} * x + \text{intersection on y axis}$) as follows:

$$\text{Simulated soft tissue depth (mm)} = 0.251 * \text{Measured length of the phantom lesion (mm)} + 20.$$

Data analysis

Data were statistically analyzed by using the SAS statistical package (Version 8, SAS Institute Inc. 1998, Cary, NC, USA). Normal distribution of the data was tested by Shapiro-Wilks test. The overall significance of the lesion contrasts and count rates were analyzed by Kruskal-Willis test. For pairwise comparison, Wilcoxon two-sample test was used to compare the difference between colour displays, digital filters, percent lesion contrasts and count rates. A p-value ≤ 0.05 was considered statistically significant.

Results

Effects of lesion contrasts

All scintigrams with 100% lesion contrast regardless of counts, color display or filtering were correctly identified as without lesion by all observers. All scintigrams with a lesion contrast of 120% and higher were detected by all observers. Lesions with 110% contrast were not detected in the 50kcounts images, but in the 150, 300 and 500kcounts images, the lesions were detected in 23, 73, and 62 percent of the images respectively.

The average maximum depths at which a lesion could be distinguished for the 110, 120, 130, 140 and 150% lesion contrasts were 3.3, 8.0, 8.9, 9.8 and 10.1 cm respectively. There was an overall statistically significant difference between the average maximum depths at which a lesion could be distinguished at the different lesion contrasts ($p < 0.0001$). The average maximum depths at which a lesion could be distinguished in 140 % lesion contrast was not statistically significant different from 150% lesion contrast but the difference from 130% lesion contrast was statistically significant ($p < 0.0001$).

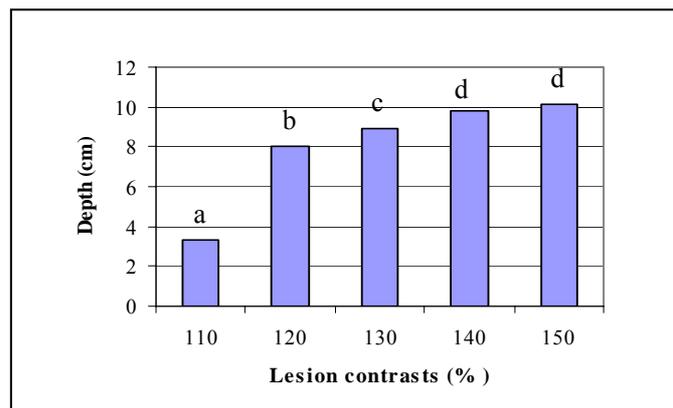


Figure 3. The effect of the lesion contrasts on the average maximum depths at which a lesion could be distinguished. The bars marked by different letters are statistically significant different ($p \leq 0.05$).

Effects of count levels

The average maximum depths at which a lesion could be distinguished for the 50, 150, 300 and 500 kcounts levels were 6.6, 8.0, 8.8 and 8.8 cm respectively. The depths with 50, 150 and 300 kcounts were statistically significant different ($P < 0.0001$) but the difference between 300 and 500 kcounts levels was not significant.

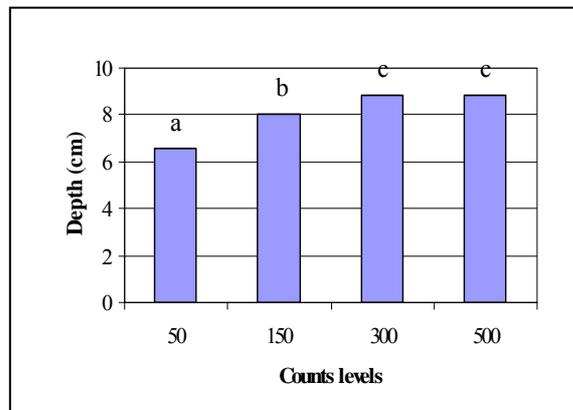


Figure 4. The effect of count levels on the average maximum depths at which a lesion could be distinguished. The bars marked by different letters are statistically significant different ($p \leq 0.05$).

Effects of digital filtering

There was no statistically significant difference in the overall detectability between filtered and unfiltered scintigrams using the same lesion contrast, counts level and color display. The linear uptake with 110% lesion contrast was detected in 40% of the filtered scintigrams and in 35% of the unfiltered scintigrams. The average maximum depths at which a lesion could be distinguished were 7.9 cm for all unfiltered and 8.2 cm for all filtered scintigrams, a difference which was not statistically significant. The digital filter significantly improved detectability of the lesion with 120% lesion contrast in 50 kcounts ($p < .0001$) and 150 kcounts ($p < 0.01$) scintigrams.

Effects of colour display

The average maximum depths at which a lesion could be distinguished were 8.0 cm in continuous blue-green-red display and 8.1 cm in continuous gray scale display. No statistically significant effect of different colour displays could be demonstrated in this study.

Discussion

A phantom like the one in this study can be used to determine the effect of overlying soft tissue and post processing on detectability of a linear lesion. The phantom simulated the equine pelvis allowing every parameter to be controlled and excluded the effect of movement. On the other hand, a phantom is just a model of reality and can and will not produce an exact copy of a live horse in every aspect.

Using a computer in the evaluation of the scintigrams made it simple to randomize the images before the observer evaluation. It would have been preferable to have all observers evaluate the images at the same time. But separate measurement of the lesions would not have been possible with all observers present at the same time. Thus individual observational evaluation using the same computer screen was considered the best choice for this study. The results provided continuous data which is desirable from the statistical point of view. An observational study like the present will take observer variation into account. However, the difference in observer experience or skill and the learning effects of the setup of the study itself should be considered. Randomization of the scintigrams before evaluation helped to decrease some of these factors.

In this study there were no false positive results, which probably is an effect of using a phantom instead of true scintigrams in which variation would be much greater. In the scintigrams with 110% to 130% lesion contrasts, the overlying soft tissue obscured the lesion resulting in loss of detectability of some length of the linear lesion. The average maximum depth at which a 110% lesion could be distinguished was low since this value included many false negative values. Smith (1987) reported that a 20% increase of the uptake in bone can be detected but in this study a lesion with a 30% increase was obscured if covered by 9 cm of soft tissue.

This study indicated that an increase in count level from 300 to 500 kcounts would not be justified since the results in these two count levels were similar. Even if true skeletal scintigrams and images made from a phantom are not the same, this suggests the presence of a compromise level in image counts as recommended in the clinical situation by several authors (Lamb and Koblik, 1988; Chambers, 1996; Dyson and Martinelli, 2003).

The digital filter increased the detectability of the lesion in the low count scintigrams (50kcount and 150 kcount) but only in scintigrams with a 120% lesion contrast. It is possible that in the 110% lesion contrast scintigrams the Metz filter produced images artifacts such as exaggerated edge packing preventing the detection of the lesion but no definite explanation was found.

There was no evidence of overinterpretation that has been mentioned by (Hornof, 1996; Weekes and Dyson, 2003) with the use of a continuous BGR colour scale compared to continuous grey scale based on the result in this study. On the other hand, the continuous BGR scale was not superior to the continuous grey scale.

The observer evaluation to decide the end point of a vanishing line with the method used in this study may involve an important bias. Once the observer has decided that the lesion (line) is present the knowledge about the construction and setup of the phantom may result in overinterpretation of the detection of the lesion. Informing the observers about the construction and setup of the phantom was done to explain the purpose of the study and to reduce the learning effect during evaluation of the images. In the future, the same phantom can be used in an observational study with a single focal lesion placed as covered with different soft tissue thickness. Such a study setup would remove the bias mentioned above. Also, the results from a study where the presence of a lesion is decided with a

degree of certainty, receiver operating characteristic (ROC) curves can be calculated which would further improve the understanding of the detectability of obscured lesions.

Conclusion

The results in this study show that in the range of the thickness of the soft tissue covering the equine pelvis (2-10.5 cm), a 110% to 130% increase in radiopharmaceutical uptake may remain undetected due to soft tissue attenuation of gamma rays. A Metz filter can improve detectability of lesion in low count level scintigrams and the continuous BGR colour scale do not cause overinterpretation. The information gained from this study should be considered when evaluating scintigrams of the equine pelvis in the clinical situation.

Acknowledgements

Suwicha Chuthatep would like to thank Sten Carlsson for being a consultant with digital filter setting and Peter Lord for help to review the article in the final stages. This study was supported by the Swedish Foundation for International Cooperation in Research and Higher Education (STINT).

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Acknowledgements

This study was carried out at the Division of Diagnostic Imaging and Clinical Pathology, Department of Biomedical Sciences and Veterinary Public Health, Faculty of Veterinary Medicine, Swedish University of Agricultural Sciences, Uppsala, Sweden. Financial support was provided by the Swedish Foundation for International Cooperation in Research and Higher Education (STINT).

I would like to express my sincere gratitude to:

Professor Peter Lord, Head of Department of Clinical Radiology, the previous name of my lovely department, for offered me the great opportunity to study in Sweden and also teaching, sharing his knowledge and experience in the clinic. Thanks for useful suggestions and unseen opinions in my study.

Dr. Per Eksell, my great supervisor, for your never-ending encouragement, for teaching me a knowledge of scintigraphic imaging as well as how to do the research and for being a wonderful supervisor who always believed in me. Apart from the scientific things, for instance, the lessons in a life style should be, troll fishing in Sunweeken lake on the beautiful summer or the step up from hell to heaven (rolling on snow and jump down to warm pool in the winter time) were wonderful and made my days very memorable. Per, you are my idol and I am very much grateful to have been your student. For word 'Thank you' is not enough to say for all you have done and have given to me over the years.

Associate Professor Karin Östenson, Director of the International Master of Science programme, for providing me the opportunity to study at SLU, Master's education.

Mieth Berger, the excellent scintigraphic technician. Big thanks for your helpful work and also your kindness together with valuable suggestions when I have done something with your unexpected which I always do.

Marie Sundberg, an excellent Master of Science course secretary, Annika Rikberg and Ingrid Österlun for all their kindly help and friendship.

Naruepon Kampa, Jatesada Jiwakanon and Weerapol Thawinan, the great brothers, for always teach and suggest all useful knowledge. Several things in my life have changed cause by you.

My colleges in the long name department that I prefer to call Department of Clinical Radiology, SLU, Kerstin Hansson, Charlotte Erichsen, Estell Ågren, Margareta Uhlhorn, Charles Ley, Anna Djupsjöbacka, Anna Olausson, Christina Larsson, Marita Blom, Peter syrjänen and other persons, being kind to me, supporting me on my work, sharing experience and their friendship.

Ewa Thebo and Lilan Löfrot, thanks for your warmth and lovely atmosphere like we still stayed in Thailand.

My classmates at the International Master science course during 2002-2004; Fernando Saravia, Bhuphender Singha, Ramon Maluping and Lihong Liu, I will never forget the friendship you gave me.

All my friends in Uppsala & Stockholm, P'Slil and Dr. Tassanee Srichaiyo, the most wonderful couple who taking care Thai student here. P'Lily, P'Ae, P'Chen, P'Alis, P'Seng, P'Nong, P'Kampon, P'Hun, P'Bunlue, P'Aun, P'How, P'Pim, P'Nort, P'Tee, P'Joe, P'Nok, Orr, Noo, N'Nok, Mark, Josefin, Clara, Henry, Ines, Monfred, Edoardo and Giliola, for spending nice time together. You guys always bring a lot of fun to me.

Professor Pranee Tuntivanich, Professor Atichat Brahmasa, Professor Anop Kunawongkrit, Professor Marissak Kalpravidh and Assistant Professor Phiwipha Kamolrat, who always supporting and giving me an opportunity to study abroad.

My colleges at department of Surgery in Thailand, P'Ju, P'Pom, P'Golf, P'A, P'Keaw, P'Kay, P'Jimmie, P'Nic, P'Ti, P'Oph, Yui, N'Gif, N.Noii, P'Umporn, P'Rat, P'Too, P'Yau and other persons, for working hard instead of me when I studied here.

Eksell family, Per, Elna, Emma, Davis and Isak, for let me know how warmly family is.

My special friends Ann Sompoprungroj and Worapot Jaturameteewong, for you guy my best friends.

Especially, I would like to express my deepest thanks to my parents, Chob and Laead Chuthatep. My aunt, Chorkeaw, and my brother Chalee, for their love, encouragement, endless support, and for making my life pleasurable and worth while, you all be in my heart eternally.

4 March 2004
Suchi / Boyd