COMPARISON OF DIRECT DIGITAL TO CONVENTIONAL FILM-SCREEN RADIOGRAPHY IN DETECTION OF EXPERIMENTALLY CREATED OSSEOUS LESIONS OF THE EQUINE THIRD METACARPAL BONE

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CHAPTER I

INTRODUCTION

Dorsal metacarpal disease

Serious musculoskeletal injury in the racehorse accounts for loss of a large number of racehorses each year. Many of these injuries involve a fracture. In addition, young Thoroughbred racehorses have a high incidence of dorsal metacarpal fractures, or “bucked shins”. Abnormalities of the equine metacarpus, such as cortical stress fractures, partial non-displaced condylar fractures, and incomplete spiral fractures of the third metacarpal bone can be difficult to diagnose without high quality imaging. These abnormalities can delay the training of young racehorses and may result in catastrophic career or life ending injuries if not diagnosed and treated appropriately. Thus, the ability to diagnose and treat these lesions early is important for the health and longevity of these racing animals.

Radiography

The diagnosis of musculoskeletal disease has involved the use of high quality radiographic images. The use of digital radiography using various types of detectors is becoming increasingly common in veterinary medicine both in academic and private practice settings. In the veterinary community, digital radiography is believed to be superior to conventional film-screen radiography on a subjective basis.

Conventional radiography involves the use of a cassette containing screens, typically rare earth, and photographic film. Processing the film occurs in a dark room, either manually or with an automated processor.

Digital radiography involves electronic acquisition of images using a re-useable image detector. The first digital radiography units first became available in the early 1980's, and these units are called computed radiography. This is a system that utilizes a cassette similar to the conventional film-screen cassette. However, instead of film, this system utilizes an imaging plate that contains a phosphostimulable phosphor screen. The x-ray energy is stored by this screen. Using an image reader, the x-ray energy is converted to light by a laser, and then to an analog signal, which is made into a digital image. Another term for this type of digital system is storage phosphor radiograpy.

The other forms of digital radiography are known as direct digital radiography, and are characterized as being either direct or indirect readout. Direct digital radiography involves the image detector to be attached to a computer through a cable or wireless connection. The direct readout detector contains selenium, and the x-ray energy is converted directly into an electrical signal. The indirect readout system contains cesium iodide photodetectors and has an additional step where the x-ray energy is first converted to visible light, then to the electrical signal. These direct digital radiography systems are also referred to as flat-panel digital radiography.

Viewing digital images may be performed by printing onto film (hard copy) or more typically by the use of a computer workstation (soft copy).

CHAPTER II

REVIEW OF LITERATURE

Dorsal metacarpal disease

Serious musculoskeletal injury in the racehorse has a reported incidence rate of 1 out of 700 starts (Peloso et al. 1994) and at least 80% of horses euthanized in race training in the United States had suffered a fracture (Johnson et al. 1994). There is evidence to support that some catastrophic fractures are the result of fatigue or “stress” fractures (Riggs 2002). In addition, Thoroughbred racehorses in early training have a 70% incidence of dorsal metacarpal fractures, or bucked shins (Norwood 1978). This type of fracture is typically located in the dorsolateral cortex of the third metacarpal bone, and is most commonly diagnosed radiographically (Nunamaker et al. 1990). The articular-based distal condylar fracture of the third metacarpal bone is also believed to be a stress or fatigue fracture (Riggs 2002). Abnormalities of the equine metacarpus, such as cortical stress fractures, partial non-displaced condylar fractures, and incomplete spiral fractures of the third metacarpal bone can be difficult to diagnose without high quality imaging. These abnormalities can delay the training of young racehorses and may result in catastrophic career or life ending injuries if not diagnosed and treated appropriately (Nunamaker et al. 1990). Thus, there is a need for high quality imaging of the metacarpus of the horse, especially when subtle lesions are suspected.

Advantages of digital radiography

There are numerous benefits by using digital radiography as compared to a conventional film-screen system. One of the benefits of digital radiography is the ability to manipulate images on the viewing monitor. This includes the ability to change latitude, contrast, and magnify images. One group concluded that magnification of a storage phosphor system (computed radiography) was superior in detection of small osseous erosions in a German shepherd dog metacarpus: a human hand model (Link et al. 1994). In addition, digital films can be manipulated post-exposure, which eliminates the need to take multiple exposures of the same anatomic region to emphasize either soft tissue or bony structures. kVP is not as much a limiting factor in obtaining diagnostic quality images in digital radiography as in conventional film-screen radiography (Mattoon 2006). The ability to take diagnostic films with a wider range of exposure settings saves both time in processing, as well as the direct costs in film and processing chemicals.

In addition, once an image is acquired, it takes just seconds to view the image instead of minutes to develop the film. This decreases the total time to finish a study (Mattoon 2006). The ability to view radiographic images on location is an additional beneficial attribute for ambulatory veterinarians who otherwise would go develop films at another site, then potentially return to the animal to repeat inadequate images or perform additional radiographic views. Finally, the ability to store and share radiographic images is a distinct advantage of digital over film-screen radiography (Mattoon 2006). Digital radiographs can easily be stored, viewed, and transferred in a picture archiving and communication system (PACS) (Mattoon 2006). Storage of digital radiographs, thus, is space saving as compared to film-screen.

Comparison of digital and conventional film-screen radiography

There has been a large volume of research in the human medical field comparing the digital radiographic systems to conventional film-screen radiography. These studies have examined the use of all three types of digital systems, have looked at diagnosis of a variety of disease conditions, ranging from soft tissue to orthopedic abnormalities, and have examined both clinical cases as well as models of human disease.

Human clinical cases

Several studies have compared computed radiography to film-screen in clinical cases with the use of musculoskeletal and thoracic soft tissue abnormalities (Wegryn 1990; Elam 1991; Swee 1997; Bonardi 2004). Three of these studies used an objective scale (Wegryn 1990, Elam 1991, Bonardi 2004), while Swee (1997) used a subjective analysis. These four studies agreed that the computed radiography system was adequate for the detection of pneumothorax, breast cancer lesions, and various musculoskeletal abnormalities.

Several other studies have compared the direct digital system to film-screen radiography in clinical cases. Woodard et al. (1998) objectively looked at identifying pulmonary nodules, and found no difference between the two radiographic systems. Piraino et al. (1999) had a subjective grading scale for grading lesion presence in hands and feet. They also concluded that there was no significant difference in the diagnostic ability of direct digital and film-screen radiography.

Human models of disease

A number of human studies have been performed comparing direct digital radiography (direct and indirect), computed radiography, and film-screen radiography. The majority of these studies have found no significant difference between the various systems (Rapp-Bernhardt et al. 2003; Rapp-Bernhardt et al. 2005; Ono et al. 2005; Ludwig et al. 2000). Each of these studies used an objective grading scale and printed out hard copies of the digital images. Link et al. (1994) compared the magnification ability of computed radiography to film-screen radiography and found that magnification improves the ability to detect small bone lesions. Strotzer et al. (2000) compared direct digital radiography to film-screen radiography in the detection of subtle osseous lesions in a hand phantom. They found that direct digital radiography was significantly better in the detection of subtle osseous lesions.

Equine study

There has been 1 published report of the comparison of a digital radiographic system to film-screen radiography. Bindeus et al. (2002) subjectively evaluated the ability to detect stifle lesions using computed radiography versus film-screen radiography. The authors found that computed radiography was superior to a 200 speed film-screen radiographic system.

Reduction of radiographic exposure

There have been a number of studies with experimental models that have examined exposure settings and their effect on the diagnostic quality of digital radiographs. Ludwig et al. (2002, 2003a, 2003b) used several animal musculoskeletal models to demonstrate that the direct digital radiographic system was superior to film-screen radiography and computed radiography when there were equal exposure settings. This group also showed that the exposure dose of the direct digital radiographic system could be reduced by 50-75% with no loss of diagnostic ability (Ludwig 2002, 2003a, 2003b). Don et al. (1999) showed that a 20% reduction of exposure settings using computed radiography did not affect pulmonary edema detection in a rabbit model, as compared to film-screen radiography. Uffman et al. (2004) compared direct digital radiography to computed radiography in the detection of musculoskeletal lesions and the impact of reducing the exposure dose. They found that direct digital radiography produced diagnostic images at 45% less exposure than the computed radiography system. Bernhardt et al. (2004) compared direct digital radiography at low, medium, and high exposure settings, and found that the lower kVp values were as effective as the high kVps in obtaining diagnostic quality images.

Hard vs. soft copies

All 3 types of digital radiographs can be viewed as laser printed hard copies or on a computer workstation as soft copies. The benefits of viewing digital radiographs as soft copies include the ability to alter contrast, latitude, and magnification of the digital image (Mattoon 2006). The diagnostic ability of digital radiographs may be altered somewhat by the type of monitor used. However, it has been found that accuracy of digital radiographs in detection of lesions is the same in high and low resolution monitors with the use of magnification (Puchalski 2008).

Brightness is an important component of a monitor, as it has been shown that accuracy is decreased with lower brightness monitors (Puchalski 2008). A conventional light box is approximately 10 times brighter than a high quality grey scale monitor, which is about 2 times brighter than a color monitor (Puchalski 2008). Thus, higher quality, higher luminance monitors may improve diagnostic ability with soft copy digital radiographs. Several human studies have compared the diagnostic ability of hard copy versus soft copy digital radiographs. A human chest phantom was used to examine two viewing monitors (low and high resolution) with hard copies (Otto et al. 1998). The hard copies were statistically superior to both monitors in lesions detection when magnification was not used. When the magnification function was utilized, the soft copies were similar to the hard copies in diagnostic ability (Otto et al. 1998).

Receiver operating characteristic (ROC) curve

The ROC curve has been used in the radiologic community to compare the ability of various diagnostic imaging modalities to discriminate between disease and absence of disease (Hanley et. al. 1982). The ROC curve can be used qualitatively (with no statistical evaluation) or the area under this curve can be assessed with statistical analysis as a more quantitative measure. The area under the curve "represents the probability that a randomly chosen diseased subject is (correctly) rated or ranked with greater suspicion than a randomly chosen non-diseased subject" (Hanley et. al 1982). In essence the ROC curve is a plot constructed of true-positives (y-axis) versus false-positives (x-axis), which would result in a single point (Bushberg et al. 2002). The ROC curve is typically constructed with 5 points, as the observer is asked to give a degree of confidence in their detection of an abnormality (definitely a lesion, probably a lesion, not sure, probably not a lesion, definitely not a lesion) (Bushberg et al. 2002). As the ROC curve moves to the left, it becomes closer to 1.0, which indicates perfect accuracy. As the curve moves to the right and reaches 0.5, the accuracy is not apparent (Hanley et. al 1982).

Purpose of study

There is considerable initial expense in purchasing a digital radiographic system, which is often justified in savings of time in imaging and assumed improved diagnostic quality of images. The initial higher cost of a digital radiographic system may be offset by reduced costs of film processing (chemicals, maintenance, film) and may also be less labor intensive (Mattoon 2006). Since soft tissue and bony structures can be examined on one image, fewer images of a specific anatomic region may need to be obtained (Mattoon 2006). In addition, the ability to repeat images on the farm instead of returning to the site of processing then having to return to the farm for additional/repeated views is a tremendous advantage in savings of time and money.

The objective of this study was to quantitatively evaluate the ability to detect experimentally created osseous lesions with conventional film-screen radiography and direct digital radiography. We hypothesized that subtle experimentally created osseous lesions of the third metacarpal bone could be more easily detected using the direct digital radiography system as compared to conventional film-screen radiography. This would justify the use of direct digital radiography in mainstream veterinary medicine.

CHAPTER III

METHODOLOGY

Specimen

Twenty four forelimbs were collected from horses euthanized for reasons other than musculoskeletal disease. Limbs were frozen after collection and stored at -4^{o}C until later use. Before dissection, the limbs were thawed at room temperature. Each third metacarpal bone was disarticulated from the limb at the carpometacarpal joint and the metacarpophalangeal joint. Metacarpal II and IV were left attached. The soft tissue structures were dissected away from the bones. After dissection, each bone was evaluated for abnormalities with a Light Speed QXI 4-slice helical computed tomography scanner (General Electric, Waukesha, WI). The third metacarpal bones were then wrapped in plastic and stored at -4^{o}C for later use.

Lesion production

Each third metacarpal bone was divided into three zones (proximal, middle, distal). The divisions were produced by drilling with a 2.8 mm (7/64 inch) drill bit using a 5.5 amp hand drill (Black and Decker, Towson, MD) through the lateral cortex at the junction between each zone (*Figure 1*). There were a total of 72 zones, and a single lesion (2 mm wide, 2.5-3 mm deep) was produced in 37 randomly selected zones (51%) (*Figures 1* and *2*).

A single lesion was produced in a randomly selected area of the dorsal cortex in its appropriate zone. Each bone contained anywhere from zero to three lesion. A lesion was produced by drilling first with a 2 mm (5/64 inch) drill bit perpendicular to the dorsal cortex at a depth of 2 mm. A rotary burr (Dremel, Inc., Racine, WI) was used to add an additional 0.05 - 1 mm to the depth of the lesion, for a total depth of 2.5 - 3 mm.

Radiography

Each bone was radiographed in a 40.64cm x 21.59cm x 10.16cm phantom box constructed of plexiglass (*Figure 3*) with the bone submerged in 99.5% glycerine (AHC Products, Inc., Winchester, KY), to simulate soft tissue covering. The glycerine completely covered the metacarpal bone, and any air bubbles directly surrounding the bone were eliminated before the bone was radiographed. The phantom was placed directly on the radiographic cassette, and the x-ray beam was collimated to exclude the margins of the phantom.

A dorsopalmar radiographic projection was taken of each bone within the phantom (*Figures 1 and 2*). Each bone was radiographed using a conventional film-screen radiographic system and a direct digital system. A Millenia CPI x-ray tube (JCF Engineering, Inc., Denver, CO) was used to obtain both digital and FSR radiographs. The Eklin Rapid Study EDR 3 with Canon flat panel indirect read-out digital radiographic system (Eklin Medical Systems, Inc., Santa Clara, CA) was used to obtain the direct digital radiographs. Conventional film-screen radiographs were obtained using 3M

Asymetrix Detail cassettes containing green light emitting rare earth screens using 350 speed film (3M, Inc., St. Paul, MN). These FSR films were processed using a Kodak Series VI Rapid Processor (Konica Minolta, Tokyo, Japan). Exposure settings (KV and mAs) were adjusted to obtain the best quality images for each radiographic system. The exposure settings for the conventional film-screen system were 60 KV, 2 mAs, and the settings for the direct digital system were 65 KV, 3.2 mAs. Both systems used a focal distance of 101.6 cm (40 inches).

FIGURE 1: Direct digital radiograph of one third metacarpal bone. The lateral cortex is marked with drill holes (large arrows) to divide the bone in proximal, middle, and distal thirds. Small arrows mark the lesions present within the proximal and distal zones.

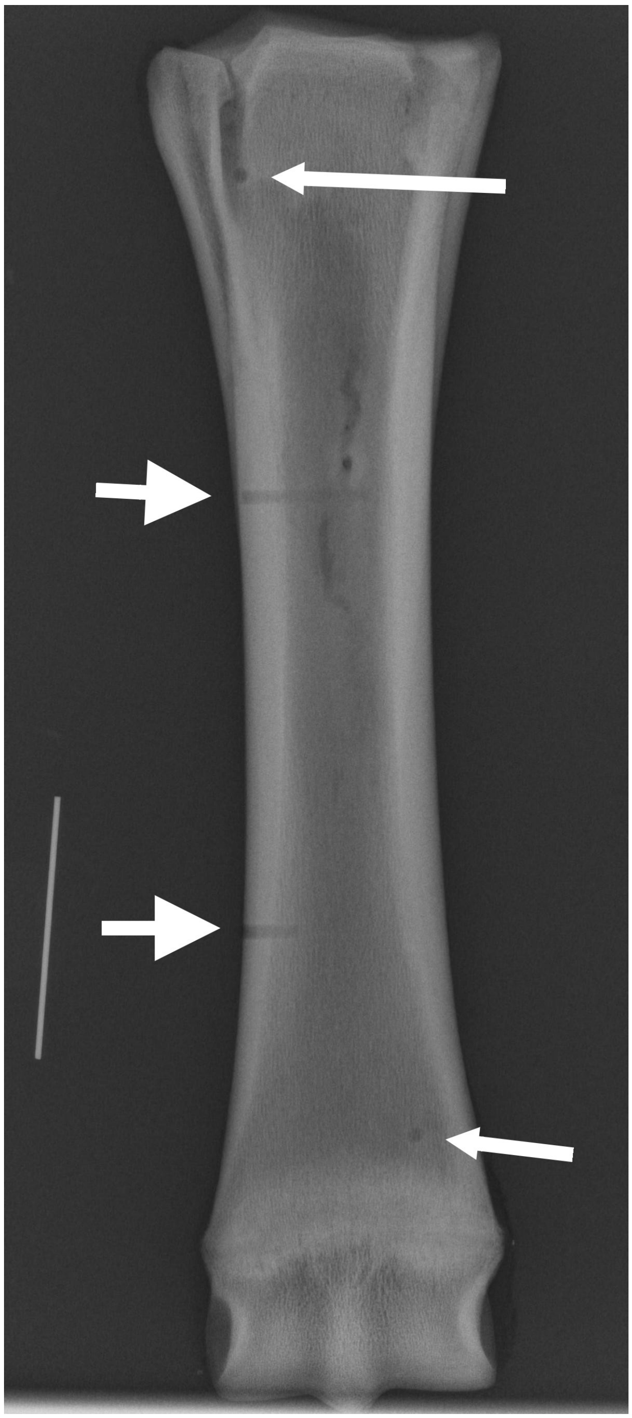

FIGURE 2: Conventional film-screen radiograph of one third metacarpal bone. The lateral cortex is marked with drill holes (large arrows) to divide the bone in proximal, middle, and distal thirds. A small arrow marks the lesion present in the middle zone.

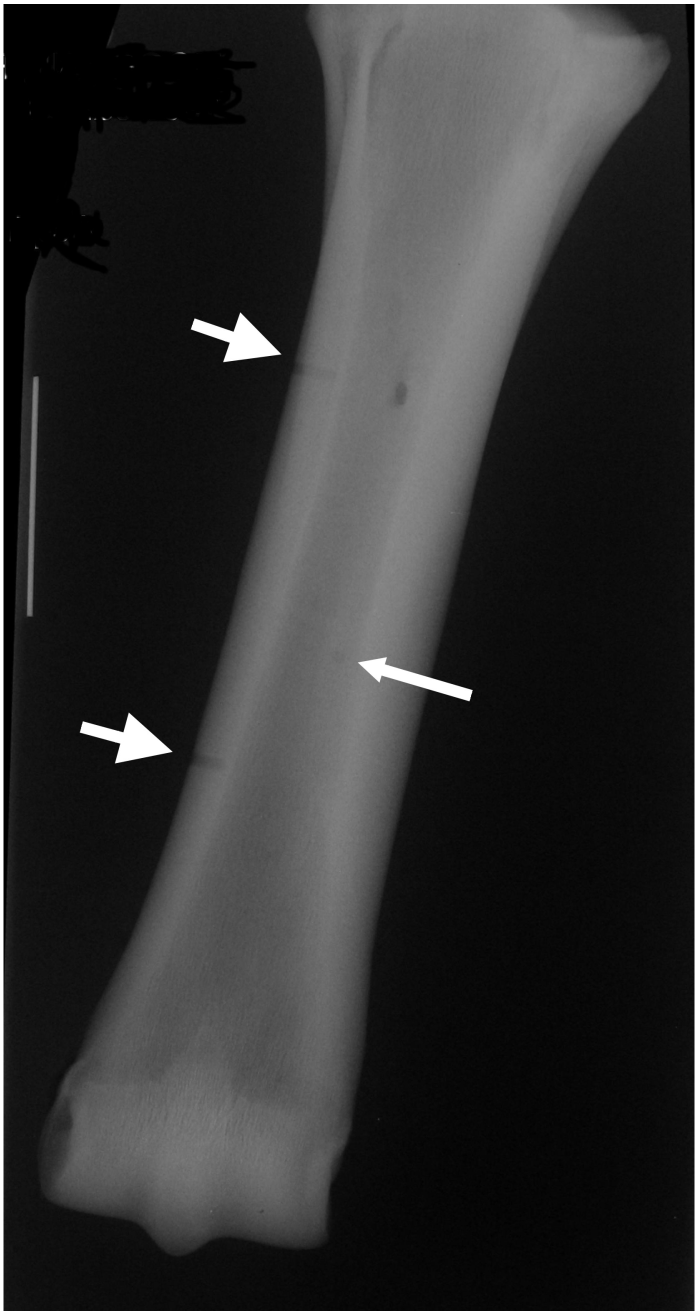

FIGURE 3: The plexiglass phantom box in which each third metacarpal bone was radiographed.

CHAPTER IV

FINDINGS

Image evaluation

Each direct digital radiograph was printed as a hard copy onto film using a FujiFilm Dry Pix printer (Fujifilm Medical Systems USA, Inc., Stamford, CT) with a pixel size of 84.7 um, a 12 bit grey scale, and image size of 35 x 43 cm. No image manipulation of the digital images was made prior to printing. There were a total of forty eight (48) radiographic projections: 24 conventional film-screen and 24 direct digital. The conventional film-screen and direct digital radiographs were combined and were randomly assigned a number between 1 and 48. Each radiologist viewed the radiographic set in the same order.

Three Diplomates of the American College of Veterinary Radiologists examined the films. They were provided a standard light box and had an unlimited amount of time to view and re-view the images. Each filled out a score card and graded each zone for the presence of a lesion using a five point scale: 1) definitely a lesion, 2) probably a lesion, 3) unsure of lesion presence, 4) probably not a lesion, 5) definitely not a lesion. The score cards for the three radiologists were pooled for a total of 216 graded zones for each radiographic system (24 radiographs, 3 zones per radiograph, 3 radiologists).

Statistical analysis

Receiver operating characteristic (ROC) curves were constructed using PC SAS Version 9 (SAS Institute, Inc., Cary, NC) and the FREQ procedure. An ROC curve was constructed for each radiographic system (direct digital and conventional film-screen). The areas under the ROC curves (and corresponding standard errors) were calculated in an effort to estimate the ability to detect a lesion. The construction of ROC curves has previously been described (Hanley et al. 1982). The two radiographic systems (direct digital and conventional film-screen) were compared using a normal test (utilizing the estimates of area under the curve and standard errors), and a p-value less than 0.05 was considered statistically significant.

Sensitivities and specificities were calculated for each radiologist for both the conventional film-screen and direct digital radiographic systems. The mean sensitivity and specificity were also calculated for each radiographic system. The presence of a lesion (grades 1 and 2) was a positive test, while the absence of a lesion (grades 4 and 5) was a negative test. Grade 3 (unsure of lesion presence or absence) was considered a negative test: always designated a false negative or false positive. A McNemar's test was used to compare the sensitivities and specificities for each radiologist for each radiographic system, as well as the mean values of sensitivity and specificity comparing each radiographic system. A p-value of less than 0.05 was considered statistically significant.

Results

The computed tomography of all third metacarpal bones revealed no abnormalities, so all 24 bones were included in lesion production.

No significant difference was found between conventional film-screen radiography and direct digital radiography for detection of subtle osseous lesions of the third metacarpal bone. The area under the ROC curves (and corresponding standard error) for the two systems (*Figure 4*) were 0.87 (0.04) and 0.90 (0.04) for conventional film-screen and direct digital, respectively. The p-value for the difference in the two areas was 0.59.

The sensitivities for each radiologist for the conventional film-screen system ranged from 0.68 to 0.81 with a mean of 0.75. The sensitivities for each radiologist for the direct digital radiographic system ranged from 0.68 to 0.86 with a mean of 0.77. The specificities for each radiologist for the conventional film-screen system ranged from 0.86 to 1.00 with a mean of 0.91. The specificities for each radiologist for the direct digital radiographic system ranged from 0.86 to 1.00 with a mean of 0.90. These values are reported in *Table 1*.

There was no statistically significant difference in sensitivity or specificity in any single radiologist when comparing conventional film-screen to direct digital radiography. When comparing radiologists to each other, there was no difference in sensitivities or specificities for film-screen or digital radiography except when comparing the direct digital sensitivities; radiologist 2 was significantly different from radiologists 1 ($p = 0.0196$) and 3 (p = p = 0.0455). When the radiologists were combined, there was no statistically significant difference in sensitivity and specificity between the conventional film-screen and direct digital radiographic systems; the p-value for sensitivity was 0.6374, and the p-value for specificity was 0.7963.

FIGURE 4: Receiver operating characteristic (ROC) curves of the direct digital and conventional film-screen radiographic systems. The area under the curve represents the ability of each radiographic system to correctly identify the presence of a lesion. There was no statistically significant difference in the areas under the curves between the two radiographic systems.

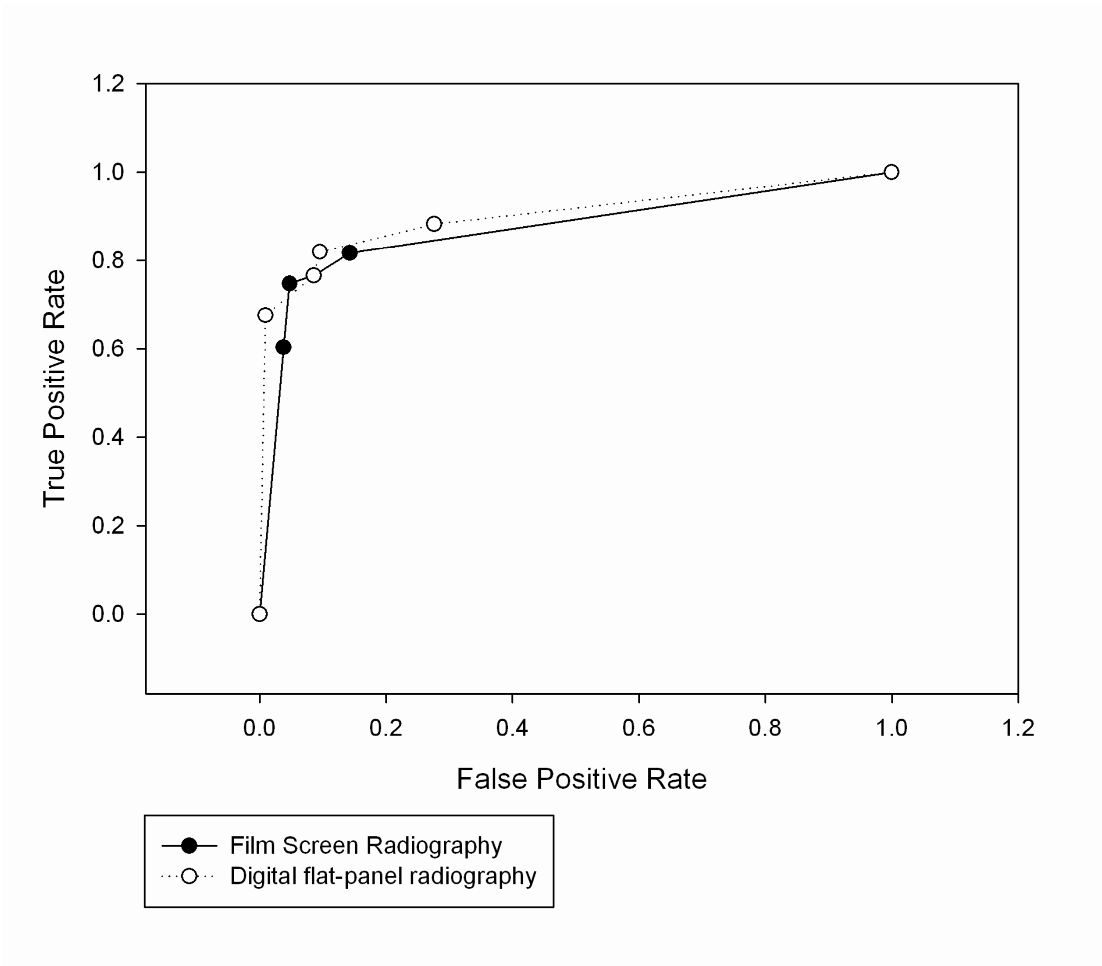

Table 1: Sensitivity and specificity of each observer for detection of experimentally created osseous lesions of the third metacarpal bone for the conventional film-screen and direct digital radiographic systems. ‡ denotes a statistically significant difference ($p < 0.05$) between radiologist 2 and radiologists 1 and 3 when comparing the sensitivity of each individual using the direct digital radiographic system.

Radiologist #	Sensitivity		Specificity	
	Film-screen	Direct digital	Film-screen	Direct digital
1	0.76	0.76	1.00	1.00
2	0.81	0.86‡	0.86	0.86
3	0.68	0.66	0.89	0.86
Mean	0.75	0.77	0.91	0.90

CHAPTER V

CONCLUSION

Discussion

Fractures among racing Thoroughbreds are not uncommon, and have been reported in anywhere from 60 to 80% in horses in the UK and United States that have been euthanized during race training (Riggs 2002). There is evidence to support that some catastrophic fractures are the result of fatigue or “stress” fractures (Riggs 2002). As many as 70% of Thoroughbred racehorses in their first year of training may develop a stress fracture, usually in the dorsolateral cortex of the third metacarpal bone, which may be visualized radiographically (Nunamaker et al. 1990). The articular-based distal condylar fracture of the third metacarpal bone is also believed to be a stress or fatigue fracture (Riggs 2002). As these two types of fractures can propagate and become catastrophic (Riggs 2002), it is important to diagnose and treat them early. Thus, there is a need for high quality imaging of the equine third metacarpus.

Digital radiography has been widely studied in the human medical literature for both soft tissue and orthopedic conditions. Several studies in the human literature have compared digital radiography to conventional film-screen radiography using laboratory animals as models for human disease. In some of these studies, digital radiography was found to be superior to conventional film-screen radiography (Ludwig et al. 2003a, 2003b; Strotzer et al. 2000). Two other human studies have demonstrated no difference in digital versus film-screen in the detection of osseous lesions (Ludwig et al. 2000; Piraino et al. 1999). While these studies have differing means of comparison (subjective assessment of normal radiographic quality versus an objective grading scale by the ability to detect lesions), the researchers agree that digital radiography is at least comparable to film-screen if not superior in examining normal structures as well as identifying osseous abnormalities.

In this study, we used an objective scale to compare direct digital radiography to high quality conventional film-screen radiography in the detection of subtle osseous lesions of the third metacarpal bone. We found that there was no difference in the detection of osseous lesions when comparing our conventional film-screen radiographic system to our direct digital radiographic system. This is supportive to the human literature as it appears that diagnostically direct digital radiography is comparable to conventional film-screen radiography in the detection of subtle osseous lesions.

The three radiologists were compared to each other by calculating sensitivities and specificities of both the conventional film-screen and direct digital radiographic systems (Table 1). All three were comparable in all aspects, except when examining sensitivity using the direct digital radiographic system. Radiologist 2 was significantly better in determining a positive test result (true positive) using the direct digital radiographic system than the other two radiologists. However, when comparing the sensitivity of conventional film-screen radiography to direct digital radiography for radiologist 2, there was no statistically significant difference.

One of the benefits of digital radiography is the ability to manipulate images on the viewing monitor. This includes the ability to change latitude, contrast, and magnify images. One group concluded that magnification of a storage phosphor system (computed radiography) was superior in detection of small osseous erosions in a German shepherd dog metacarpus: a human hand model (Link et al. 1994). As the benefits of magnification and image manipulation have already been widely accepted, in this study we decided to compare the two radiographic systems using hard-copies. In addition, this study was modeled after several human studies, which used hard copies of digital radiographs in their comparisons to conventional film-screen radiography (Ludwig et al. 2000,2002,2003a,2003b; Rapp-Bernhardt et al. 2003).

There have been several studies, which have compared hard-copy digital images to digital images viewed at a workstation (soft copies), as well as to conventional film-screen radiographs. These studies have provided mixed results, with one resulting in improved results in the detection of lesions using a workstation (soft copies) (Link et al. 1994), while others showed no significant difference between the two digital viewing options (soft versus hard copies) (Elam et al. 1992; Lund et al. 1997). In a human study of simulated pulmonary lesions, hard copies were compared to two types of monitors (high and low resolution), and the hard copy films were found to be superior to both types of soft copy viewers in lesion detection when no magnification was used (Otto et al. 1998). With the added benefit of magnification, the two monitor systems were found to be comparable to the hard copies in detection of lesions (Otto et al. 1998). A more recent study revealed no statistically significant difference when comparing conventional film-screen radiographs to computed radiography using both hard and soft copies (Weatherburn et al. 2003). As the majority of these studies are > 10 years old, it is possible that technological advances to workstation equipment may alter these previous findings. However, extrapolating from the findings of these previous studies, hard copies were chosen for use in our study.

Laser-printing the direct digital films may have an effect on the image, as there may be an increase in grey scale of the image. This potentially could result in more conspicuous lesions. This could have impacted the radiologists' ability to detect lesions in the digital set of images, and the ROC value for the direct digital radiography system may be falsely low. However, results of previous studies have not yet substantiated this view (Otto et al. 1998; Weatherburn et al. 2003). As many studies comparing digital hard copies to workstations are older (> 10 years) and involve computed radiography, it may be beneficial to compare the detection of subtle osseous lesions using workstation monitors, in addition to hard copy direct digital images, to determine if there are differences between these viewing options compared to conventional film-screen radiography.

The use of hard copies does not provide the most ideal circumstances for comparison between conventional film-screen and direct digital radiography. However, the use of a PACS workstation has its own set of uncontrolled variables, such as luminance, monitor type (LCD or cathode), resolution of the monitor, and age of the monitor (Puchalski 2008). While low and high resolution monitors with the benefit of magnification have been found to be similar for diagnostic capabilities, there is still evidence that high resolution monitors are superior in some cases (Puchalski 2008). In a research setting, the same monitor with similar conditions can be utilized. However, when extrapolating research findings to a clinical setting where a lower quality monitor may be used, it may make these findings less valuable.

The radiologists in our study were not blinded to source of the radiographs, and digital radiographs can be distinguished from the conventional film-screen radiographs. This is a potential source of bias in this study. The direct digital images and conventional film-screen images were randomly ordered so each radiologist did not examine each system individually. As digital images are routinely viewed at a workstation, our results may be altered by having the radiologists review the digital images as hard-copies. A PACS workstation could have been used, but with this viewing option, the digital and conventional film-screen images could not be viewed collectively as one set of images. There are numerous benefits by using digital radiography as compared to a conventional film-screen system. First, digital films can be manipulated post-exposure, which eliminates the need to take multiple exposures of the same anatomic region to emphasize either soft tissue or bony structures. kVP is not as much a limiting factor in obtaining diagnostic quality images in digital radiography as conventional film-screen radiography (Mattoon 2006). Previous reports demonstrated that there are a wide range of exposures that resulted in diagnostic quality images (up to 75% dose reduction) (Ludwig et al. 2002, 2003a, 2003b). The ability to take diagnostic films with a wider range of exposure settings saves both time in processing, as well as the direct costs in film and processing chemicals. In our study, we chose not to look at reduction of x-ray exposure in the ability to obtain diagnostic radiographs. While digital radiographs can be diagnostic with lower exposure settings, better detail is accomplished with higher settings (Rapp-Bernhardt et al. 2005), and we wanted to compare the diagnostic capabilities of our two radiographic systems at their optimal exposure settings. In this study, we compared a direct digital radiographic system (indirect read-out) to the conventional film-screen radiographic system used at our referral institution. The exposure settings were not identical for the two radiographic systems; the exposure settings used in this study produced the best images for each individual radiographic system. In addition, the direct digital radiographs were not manipulated prior to laser-printing. There are conventional film-screen radiographic systems (single emulsion film, single screen cassette) that provide higher detail images, which have been used clinically for evaluation of dorsal metacarpal stress fractures. Future research could examine the use of this type of higher quality conventional film-screen system in comparison to direct digital radiography in the detection of osseous lesions.

Another added benefit of digital radiography is that once an image is acquired, it takes just seconds to view the projection instead of minutes to develop the film. This decreases the total time to finish a study (Mattoon 2006). The ability to view images on location is an additional beneficial attribute for ambulatory veterinarians who otherwise would go develop films at another site, then potentially return to the animal to repeat inadequate images or perform additional radiographic views. However, while a veterinarian may be able to view images, he may not have the ability to fully diagnose lesions on site depending on the type of digital system and workstation set up. Finally, the ability to store and share radiographic images is a distinct advantage of digital over film-screen radiography (Mattoon 2006). Digital radiographs can easily be stored, viewed, and transferred in a picture archiving and communication system (PACS) (Mattoon 2006). Storage of digital radiographs, thus, is space saving as compared to conventional film-screen radiographs.

Spatial resolution is important in image quality in imaging the skeleton, and digital radiology has been found to be inferior to conventional film-screen systems (Mattoon 2006). High quality conventional film-screen radiographs have spatial resolution of 7 line-pairs/mm or more, while the current digital and computed radiographic systems have 2.5 to 5 line pairs/mm (Mattoon 2006; Widmer 2008). The less expensive digital units used in veterinary medicine may have even less spatial resolution (2 line pairs/mm) (Mattoon 2006). Digital radiography's inferiority to conventional film-screen radiography in this aspect is becoming less important as digital radiographic systems improve (Mattoon 2006). In addition, there is a limit in how much spatial resolution the human eye can appreciate, so some decrease in spatial resolution by digital radiography may have less importance (Mattoon 2006). At a distance of about 25 cm, the human eye can resolve 5 line pairs/mm (Huda et al. 2003), which is at the resolution of current high quality digital radiographic units.

This study was performed in cadaver limbs with artificially produced lesions. The ROC curve is best applied in this situation versus clinical cases, since true positives are difficult to impossible to define in clinical cases (Link et al. 1994). The benefit of this model is that the presence of the lesion was known. There have been previous reports in the human literature in the comparison of digital radiography and conventional film-screen radiography with the use of lesion stimulation by both drilling and induction of fractures in bone (Ludwig at al. 2002, 2003a, 2003b). In this study, we decided to produce lesions with a drill because they are easily produced as well as reproducible. However, third metacarpal lesions in clinical cases would not typically be of the same circular configuration as demonstrated in this study, and there would be a wider array of types of lesions that would not all be detectable on just one radiographic view. In a clinical case, multiple radiographic views would be obtained with the hope that in at least one view, the x-ray beam would be tangential to the lesion. In this study, we simplified this by only taking the radiographic view that highlighted the experimental lesion. Although this model does not adequately mimic clinical cases, it was adequate to test our hypothesis of the ability to detect a subtle osseous lesion.

The production of an adequate lesion was also a challenge. The lesion needed to be visible yet subtle to adequately test the diagnostic abilities of the two radiographic systems. The use of a drill bit alone resulted in a lesion that was very visible, while the burr alone created a lesion that was not visible. The combination of the two seemed to make lesions that were more subtle, yet visible. With the same diameter lesion, the interpreters would be susceptible to additional bias. Varied diameter lesions were experimented with. However, it was determined that the 2 mm drill bit produced the most subtle osseous lesion.

Additionally, soft tissues cover lesions in clinical cases, unless open wounds are present. In this study, the third metacarpal bones were contained in a phantom, and were covered in glycerine solution to simulate soft tissue covering. The glycerine obliterated the gas-bone interface, which approximates a soft tissue covering. The use of a phantom or container and simulated soft tissue covering (plastic and water) has been previously reported (Ludwig et al. 2003; Strotzer et al. 2000). The phantom used in this study was made large enough to contain the metacarpal bones as well as to allow the collimation of the x-ray beam so that the edges of the phantom were not included within the radiographic image. The density of 100% glycerine[a] at 20°C is 1.26 g/cm^3, which is higher than the density of muscle (1.04 g/cm^3) (Berry et al. 2002). Water could have also been used, which has a density of 1.00 g/cm^3. A 17-18% glycerine-water solution would have been the best approximation of soft tissue density (1.04 g/cm^3), but this produced a micelle-like solution, and could have resulted in artifacts when radiographed. While 99.5% glycerine is not the same radiodensity as soft tissues, a consistent amount was used to cover each bone so it should not affect the comparison between the two radiographic systems. Potentially, a distal limb could have been used with soft tissues intact. This would eliminate the need for both the phantom and the soft tissue simulation. However, this may have made production of the lesions more difficult, as soft tissue structures may have been damaged and made drilling in the bone more difficult. Additionally, drilling holes through a layer of soft tissue would have left a gas-filled tract, which would have made the lesions much less subtle in a radiographic image.

Conclusions from our study

In this study, our hypothesis that the direct digital (indirect read-out) radiographic system would be superior to high quality conventional film-screen radiography in the detection of subtle osseous lesions was not supported. We found that there was no significant difference in the diagnostic abilities of the two radiographic systems in the detection of subtle osseous lesions of the third metacarpal bone of the horse. However, examining the direct digital images using soft copies may provide differing results, and would be an avenue for further study. As digital radiography has many other distinct advantages over a conventional film-screen radiographic system, the use of direct digital radiography can still be advocated.

FOOTNOTES

a. Density of Glycerine-Water Solutions [page on the internet]. Midland, MI: Dow Chemicals Company; c1995-2009 – [cited 2009 March 31]. Available from: http://www.dow.com/glycerine/resources/dens_sg.htm

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VITA

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Thesis: COMPARISON OF DIRECT DIGITAL TO CONVENTIONAL FILM-SCREEN RADIOGRAPHY IN DETECTION OF EXPERIMENTALLY CREATED OSSEOUS LESIONS OF THE EQUINE THIRD METACARPAL BONE

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Scope and Method of Study: Dorsal metacarpal disease is a significant cause of wastage in young racehorses. Radiography is a common tool in the diagnostic workup of horses with suspected dorsal metacarpal lesions. Human radiographic studies have examined digital radiography to conventional film-screen radiography in the detection of both soft tissue and osseous lesions. These studies maintain that digital radiography is as good as conventional film-screen radiography in detection of lesions, and a few of these studies show that digital radiography is superior to conventional film-screen radiography. There is only 1 equine study using a subjective analysis, which concludes that computed radiography is superior to film-screen radiography. This thesis describes the methodology and analysis of an objective comparison between direct digital and conventional film-screen radiography. Experimentally created lesions were produced in the dorsal cortex of twenty-four third metacarpal bones. Three diplomats of the American College of Radiology examined 48 dorsopalmar radiographs (24 digital and 24 film-screen) of these third metacarpal bones and ranked their ability to detect a lesion using a 5 point grading scale.

Findings and Conclusions: There was no statistically significant difference in the detection of subtle osseous lesions when comparing direct digital radiography to conventional film-screen radiography. This data does support the use of direct digital radiography as it is at least comparable to the diagnostic ability of conventional film-screen radiography.

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