Clinical Radiology of the Horse

Fourth Edition

JANET A. BUTLER
B&W Equine Group, Berkeley, UK

CHRISTOPHER M. COLLES
BVetMed, PhD, MRCVS, Hon FWCF
Avonvale Veterinary Practice Ltd., Banbury, UK

SUE J. DYSON
MA, VetMB, PhD, DEO, FRCVS
Centre for Equine Studies, Animal Health Trust, Newmarket, UK

SVEND E. KOLD
DVM, Dr Med Vet, CUEW, RFP, MRCVS
Svend Kold Ltd., Tetbury, UK

PAUL W. POULOS
JR, DVM, PhD, DipACVR
California, USA

With contributions from SARAH PUCHALSKI
DVM, DipACVR
California, USA
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABOUT THE AUTHORS</td>
<td>v</td>
</tr>
<tr>
<td>PREFACE TO THE FOURTH EDITION</td>
<td>vii</td>
</tr>
<tr>
<td>ABOUT THE COMPANION WEBSITE</td>
<td>ix</td>
</tr>
<tr>
<td>1 GENERAL PRINCIPLES</td>
<td>1</td>
</tr>
<tr>
<td>Introduction, 1; Principles of radiography, 3; Principles of radiographic interpretation: radiology, 15; Radiological appearance of physiological changes and some common pathological lesions, 20</td>
<td></td>
</tr>
<tr>
<td>2 COMPUTED AND DIGITAL RADIOGRAPHY</td>
<td>41</td>
</tr>
<tr>
<td>3 THE FOOT</td>
<td>55</td>
</tr>
<tr>
<td>Distal phalanx (pedal bone), 55; Hoof, 97; Navicular bone, 113</td>
<td></td>
</tr>
<tr>
<td>4 THE PROXIMAL AND MIDDLE PHALANGES AND THE PROXIMAL INTERPHALANGEAL JOINT</td>
<td>149</td>
</tr>
<tr>
<td>5 METACARPOPHALANGEAL AND METATARSOPHALANGEAL (FETLOCK) JOINTS</td>
<td>175</td>
</tr>
<tr>
<td>6 THE METACARPAL AND METATARSAL REGIONS</td>
<td>215</td>
</tr>
<tr>
<td>7 THE CARPUSS AND ANTEBRACHIUM</td>
<td>259</td>
</tr>
<tr>
<td>8 THE SHOULDER, HUMERUS, ELBOW AND RADIUS</td>
<td>301</td>
</tr>
<tr>
<td>Scapulohumeral (shoulder) joint and humerus, 301; Humeroradial, humeroulnar and radioulnar (elbow or cubital) joints and radius, 330</td>
<td></td>
</tr>
<tr>
<td>9 THE TARSUS</td>
<td>349</td>
</tr>
<tr>
<td>10 THE STIFLE AND TIBIA</td>
<td>399</td>
</tr>
<tr>
<td>Stifle, 399; Tibia, 440</td>
<td></td>
</tr>
<tr>
<td>11 THE HEAD</td>
<td>449</td>
</tr>
<tr>
<td>Cranium, 451; Paranasal sinuses (frontal, maxillary, conchal) and maxilla, 466; Teeth and mandible, 480; Pharynx, larynx and Eustachian tube diverticulum, 512</td>
<td></td>
</tr>
<tr>
<td>12 THE VERTEBRAL COLUMN</td>
<td>531</td>
</tr>
<tr>
<td>Cervical vertebrae, 531; Thoracolumbar vertebrae, 569; Sacrum and coccygeal vertebrae, 602</td>
<td></td>
</tr>
</tbody>
</table>

[iii]
Contents

13 THE PELVIS AND FEMUR 609
  Pelvis, 609; Femur, 632

14 THE THORAX 639

15 THE ALIMENTARY AND URINARY SYSTEMS 687
  Oesophagus, 694; Abdomen and gastrointestinal tract, 705; Urinary system, 715

16 MISCELLANEOUS TECHNIQUES 723
  Arthrography and bursography, 723; Tendonography, 724; Angiography, 725;
  Venography, 730; Myelography, 733; Pneumocystography, 743;
  Intravenous Pyelography, 744; Other techniques, 744

APPENDIX A: FUSION TIMES OF PHYSES AND SUTURE LINES 749

APPENDIX B: EXPOSURE GUIDE, IMAGE QUALITY AND FILM PROCESSING FAULTS 753

APPENDIX C: GLOSSARY 761

INDEX 767
Janet A. Butler
Jan has specialised in equine radiography and has 40 years’ experience in this field. She joined the Animal Health Trust in Newmarket in 1975 where she gained considerable experience working with many internationally renowned veterinary surgeons. Since 1997 she has been working in private practice, initially at the Willesley Equine Clinic in Gloucestershire, which since 2009 has been part of the B&W Equine Group.

Christopher M. Colles
Chris qualified from the Royal Veterinary College, London in 1971. After three years in mixed practice (where he obtained a Part I Diploma in Radiology) he joined the Animal Health Trust as a clinician in 1975. He was awarded a PhD for work on Navicular Disease in 1981, and has carried out research in many areas of equine orthopaedics and radiology, having a particular interest in the horse’s foot. In 1988 he returned to practice, where he became a senior partner in Avonvale Veterinary Practice, specialising in equine orthopaedics, until his recent retirement from practice. Chris still carries out some second opinion veterinary work, and teaching. He is recognised by the Royal College of Veterinary Surgeons as a Specialist in Equine Orthopaedic Surgery. Chris was awarded an Honorary Fellowship of the Worshipful Company of Farriers in 2000 in recognition of his research into conditions of the foot, and involvement with farriery education.

Sue J. Dyson
After qualifying from the University of Cambridge in 1980, Sue worked for a year at New Bolton Center, University of Pennsylvania, and then spent a year in private practice in Pennsylvania. Sue then joined the Centre for Equine Studies of the Animal Health Trust, Newmarket, where she has specialised in lameness diagnosis and diagnostic imaging. Sue is recognised as a Specialist in Equine Orthopaedics by the Royal College of Veterinary Surgeons and holds the RCVS Diploma in Equine Orthopaedics. She is an Associate of the European College of Veterinary Diagnostic Imaging. She has published widely on lameness, radiography, ultrasonography, nuclear scintigraphy and magnetic resonance imaging.

Svend E. Kold
Svend qualified from The Royal Veterinary and Agricultural University in Copenhagen in 1979. He then spent over 10 years at the Animal Health Trust in Newmarket, where he completed his Dr.Med.Vet Thesis on femorotibial subchondral bone cysts. After a sabbatical year at Colorado State University, he joined the Willesley Equine Clinic, Gloucestershire in 1991, where he was a partner until 2009. He is now a private consultant. He specialises in lameness
and orthopaedic diagnostics and surgery and is recognised as a Specialist in Equine Orthopaedic Surgery by the Royal College of Veterinary Surgeons. He is veterinary consultant to a European equine insurance company and is involved as an expert in many equine legal cases, both in the UK and Europe. He has published regularly on orthopaedic subjects.

Paul W. Poulos
Following graduation from the University of California at Davis in 1960, Paul founded a private practice. In 1972 he returned to Davis to specialise in radiology where he became Diplomate of the American College of Veterinary Radiology. He moved to the Royal Veterinary College of Stockholm, Sweden and was awarded a Veterinary Medicine Doctorate (PhD) for his thesis on osteochondrosis in 1977. He was Associate Professor of Radiology at the University of Utrecht, and on return to the USA, was Professor of Radiology at University of Florida. From 1983, he was chairman of the Department of Radiology. In 1990 Paul left academia to establish his own consulting practice, Poulos Veterinary Imaging, based in Ukiah, California. He has published widely on osteochondrosis, navicular disease and diseases of the fetlock. Paul is now retired and has not contributed to the fourth edition of the book.

Sarah Puchalski
Following graduation from the University of Saskatchewan in 1999, Sarah worked for two years at New Bolton Center, University of Pennsylvania. In 2001 she moved to the University of Davis, California to specialise in diagnostic imaging. In 2004, she was awarded Diplomate of the American College of Veterinary Radiology. After 12 years in the diagnostic imaging department of the University of Davis, California, Sarah recently moved into private practice in California, but remains Adjunct Associate Professor of Diagnostic Imaging, Department of Surgical and Radiological Sciences, School of Veterinary Medicine, University of California, Davis. Sarah has published widely on many aspects of diagnostic imaging.
Preface to the fourth edition

When we wrote the first edition of *Clinical Radiology of the Horse*, it was with the intention of providing a comprehensive book dedicated to equine radiography and radiology which would be of practical help to the practitioner, as well as providing specialist information. We have now evolved to the fourth edition, but our aims remain the same. The authors have all practised radiography and radiology and have pooled our collective knowledge and experiences to write a book by consensus, rather than a multi-author text. This has tested the patience and endurance of us all, but we hope that it continues to enhance the value of the book to the reader.

We thank Paul Poulos who contributed extensively to the first three editions of the book, but having now retired has opted out of involvement with the fourth edition. We wish him well for the future. We welcome Sarah Puchalski who has contributed to three of the chapters in the fourth edition, and whose additional expertise we hugely appreciate. Once again Geoff Lane has cast his knowledgeable eye over the chapter on the head, and we are grateful for his assistance in this area, while acknowledging that any errors remain our own.

We have continued to update the text of the book, reflecting advances in our own knowledge and collective experiences and incorporating relevant new published material. We are aware that there are some readers who would prefer this to be a referenced text, but that does not fit with our original aims. We have however endeavoured to include in the Further Reading lists comprehensive references not only to radiography and radiology, but also to complementary imaging techniques including ultrasonography, scintigraphy, computed tomography and magnetic resonance imaging. In some chapters these references have been collected together to refer to specific anatomical regions and conditions. In the text, which continues to focus on radiography and radiology, we make reference to other imaging techniques where they may provide valuable additional information.

We realise that in many parts of the world digital imaging has superseded conventional film-screen radiography; however, we hope that this text will continue to be used worldwide, and so we have maintained references to conventional radiography. Whatever method of radiography is used, we believe that attention to the basic details of patient preparation, positioning, exposure values and appropriate collimation are crucial for optimal image quality.

We have replaced the majority of figures with digital images, but there are a few examples of relatively unusual conditions illustrated using conventional film-screen images. We have greatly expanded the number of images by providing additional figures online. This has enabled us to provide many more examples both of normal variants and a variety of abnormal conditions. We hope that the detailed figure legends will encourage readers to evaluate
Preface to the fourth edition

radiographs systematically, describing each abnormal feature, before establishing a differential diagnosis list, rather than ‘lesion spotting’.

The majority of the images in the fourth edition were provided by the Animal Health Trust, Avonvale Veterinary Practice, B & W Equine Hospital, Willesley Equine Clinic, and the University of Davis, California, to all of whom we are grateful. We thank J. Weaver, S. Stover and T. O’Brien and the Equine Veterinary Journal for figures illustrating soft-tissue attachments in the fetlock and pastern regions and B. Maulet, I. Mayhew, E. Jones and T. Booth and the Equine Veterinary Journal for figures illustrating soft-tissue attachments in the stifle. We also thank all the veterinarians who have supplied figures which illustrate conditions which we did not have in our archives, who are cited in the legends of their respective figures.

We have all learnt from professional colleagues around the world and thank them for sharing their knowledge and experiences and also providing some constructive criticisms of previous versions of the book, which we hope have enhanced the current edition. We are enormously grateful to our wives, husbands, partners and friends, without whose willing support this book could never have been completed.

Janet A. Butler
Christopher M. Colles
Sue J. Dyson
Svend E. Kold
About the companion website

This book is accompanied by a companion website:

www.clinical-radiology-horse.com

The website includes:
• Over 200 additional figures
• All the figures from the book
• A full list of further reading references from the book, with CrossRef hyperlinks

All the figures, including those available on the companion website, are cited in the printed book. Those that are prefixed with the letter ‘w’, e.g. Figures 1w.4c–f, appear online only. They are not in the printed book or e-book formats.

Access to the website requires a password – there is a prompt on the website about how to obtain the password.
Chapter 1
General principles

INTRODUCTION
There are many books that describe the principles of radiography. This book does not attempt to provide detailed information in this area, and readers who do not have a working knowledge of radiography are advised to consult one of the standard texts in order to obtain the necessary understanding of radiographic physics. This book does aim to provide up-to-date information specific to the horse. As various forms of competitive and pleasure riding have become more popular, the demand on veterinary surgeons to provide the highest quality of treatment has increased. Similarly radiography of the horse in sickness as well as in health, for insurance and purchase examinations, has increased. The book is intended for all who radiograph horses and read radiographs, be they equine specialist, general practitioner or student. It gives information on equipment required, radiographic techniques, positioning, and the views required to examine the various areas of the horse adequately. It also provides information on the normal radiographic anatomy of the immature and skeletally mature horse, variations, and incidental findings. Finally it gives information on the types of lesion that may be detected, with examples of as many of the more common problems as practical, as well as brief clinical remarks where appropriate. The ‘Further reading’ lists at the end of each chapter are not intended to be complete lists of every paper written on the subject of the chapter. They list references that the authors consider of particular interest, and that are complementary to the text. Many of these references give more detailed information in specific areas than can be justified in a textbook of this type.

Interpreting the clinical significance of radiological changes is always difficult. We set out to indicate certain lesions that may always be regarded as clinically significant, and some that are known to have no clinical significance. The section in each chapter on ‘Normal variation and incidental findings’ attempts to differentiate between variations that have no clinical significance at any time (e.g. radiolucent lines in the fibula, that represent remnants of separate centres of ossification) and those that may be clinically significant for a specific but limited period of time, and therefore require further clinical investigation to determine their significance (e.g. enthesophyte formation). The radiograph is only a reflection of the state of the tissues at the fraction of a second when they were radiographed. There are many findings which indicate a past event that has ‘left its mark’, but which
is no longer clinically significant. For example, entheseophyte formation at the insertion of a ligament may indicate a sprain to that ligament at some time in the past. As entheseophytes take time to form, once they are visible on radiographs they no longer represent an acute injury, but are the result of an incident that occurred at least several weeks previously; on the other hand, their radiographic appearance might be used to approximate their age.

Radiography is a continually developing science, and as more powerful and sophisticated equipment becomes generally available, the diagnostic possibilities for veterinary practitioners become ever greater. It is hoped that this book will enable veterinarians to get the best out of their equipment, to obtain diagnostic radiographs, and to give a correct and meaningful diagnosis from the radiographs. The information in the text has been collated from the literature where possible, and complemented by the authors’ experience. In some areas, however, there is no published work, or published information is contradictory. In these circumstances the authors have relied on their own collective experience, but have only presented information if all the authors are in agreement. (For example, reported physeal closure times for some physes vary widely between texts. The times given are based on the authors’ experience of radiographic closure, in some cases backed up by radiographic examinations of animals specifically to aid completion of this text.) The authors are experienced clinicians who routinely obtain and read equine radiographs, and it is hoped that the broad range of experience that they offer to the reader will prove to be of practical value. It is important to remember that, as radiography is a developing science, ‘new’ lesions and radiographic views are continually being found and described, and no text can hope to be complete when published, let alone as time progresses.

This text has made use of current terminology. *Nomina Anatomica Veterinaria* (5th edition, 2005) was consulted for anatomical terms and names. In some instances we refer first to the correct nomenclature, but make subsequent reference to the more commonly used colloquial name (e.g. distal sesamoid bone and navicular bone). It should be noted that long bones have cortices and a myeloid cavity (the medulla), sesamoid bones and short bones (e.g. the central and third tarsal bones) have compact bone and spongiosa. Radiographic views are described using the method advocated by the American College of Veterinary Radiologists, which first describes where the x-ray beam originates relative to the horse (e.g. dorsolateral), then where the beam is directed to (e.g. palmaromedial) (i.e. dorsolateral-palmaromedial oblique). Reference to Figure 1.1 may help to elucidate the current terminology used. While at first sight this may appear cumbersome, it does provide a specific description of the views, which allows them to be reproduced accurately. Terminology in common usage is included in parentheses and serves only to maintain continuity with other texts and references. A glossary (Appendix C) is also included and lists former and current scientific terminology as well as common lay terms.

We have not set out to provide radiographs of every variation of all lesions. Rather we have given typical examples of lesions, and in the text have indicated how these may vary. We also hope that the reader will use this text as a basis to understand why certain types of radiographic lesions form, and the processes that are likely to cause them, so that an inexhaustible supply of radiographic variations would be superfluous. Although we have done our utmost to find radiographs that reproduce well, we ask the reader to
remember that inevitably some detail is lost in the process of transferring radiographs to print, however all images can be viewed on the website, and this also provides additional images that are not present in the printed version.

PRINCIPLES OF RADIOGRAPHY

The following paragraphs serve only as a reintroduction to the subjects of image production and differentiation. For more detailed information the reader is referred to the standard radiography texts. It is important that any radiograph is of maximum quality and yields sufficient detail to allow subtle radiographic lesions to be detected.

Production of x-rays

An x-ray beam consists of high-energy electromagnetic radiation. It is produced by accelerating a beam of electrons into a tungsten target. This results in the production of a beam of x-rays, and the liberation of considerable energy as heat. A small target area produces a narrower beam of x-rays, and better definition on the resultant radiograph than a larger target area. The area of the target struck by electrons is called the ‘focal spot’. Ninety-nine percent of the energy from the electron beam is given off as heat, not x-rays, and so there is a risk of the target being melted. Dissipating this heat and keeping the target as small as possible are major factors in design of x-ray tubes. For generators with a large output, the target in the tube is the edge of a disc. By rotating the disc at very high speeds during x-ray production, the area being heated is continually being changed, allowing a small focal spot in spite of high output. This is standard in large static x-ray generators.

Figure 1.1 Correct nomenclature to describe various aspects of the horse.
Smaller mobile or portable generators generally have fixed targets, which does limit the output possible. Any x-ray beam is made up of photons of mixed wavelengths. The older half- and full-wave rectification in small x-ray generators resulted in very marked variations in the energy of the individual photons of the x-ray beam. The high-frequency generators currently available have greatly improved the consistency of the x-ray beam produced, causing less scatter and a better resultant image.

**Production of a radiographic image**

An image is created by detecting the differential absorption of x-rays that pass through an object placed in the path of the primary x-ray beam. The x-rays that pass right through the object are either detected using conventional x-ray film, or digital images are created (see Chapter 2). The number of x-rays that are absorbed by a given thickness of a specific tissue varies between tissues, and thus affects the number of x-rays passing through to form the image. For example it is more difficult to penetrate bone than air, and therefore less x-rays reach the film if they have to penetrate bone rather than air. The areas of the image relating to relatively unobstructed x-rays are black, whereas the areas protected by bone, which absorbs or deflects a proportion of the x-rays, are paler or white. Intermediate densities of tissues produce variable shades of grey. Fat is the least dense tissue, and gives relatively black tones, with muscle and bone giving increasingly light tones. It is the juxtaposition of these tissues of varying densities that allows differentiation of form and structure.

**Exposure factors**

Exposure factors affect the opacity and contrast of the radiographic image. The quantity of photons (x-rays) reaching the film (or digital sensor) affects opacity (blackness). This is primarily controlled by the milliampere (mA), higher mA resulting in a greater number of photons being produced in the x-ray beam. By lengthening the time for which the beam is produced, the total number of photons is increased in proportion, i.e. doubling the time, doubles the number of photons reaching the film. This is normally recorded for any exposure as mAs, i.e. mA times time (milliampere seconds).

A major factor influencing the number of photons reaching the film is the distance of the film from the focal spot. This is known as the focus–film distance (FFD), or the source–image distance (SID). Because the x-ray beam spreads out to cover a two-dimensional area, the number of photons reaching the film falls as a square of the distance. This means that changing the distance by a relatively small amount can have a marked effect on image opacity, although it has only a minor effect on contrast, because all areas experience a similar percentage drop in numbers of photons reaching the film.

The kilovoltage (kV) governs the energy of the x-rays and their ability to penetrate through tissue. The higher the kV, the greater the energy of the x-rays, and the greater their ability to penetrate tissues. This has some effect on opacity, but more importantly affects contrast. Soft tissues such as fat and muscle absorb limited numbers of x-rays, even of low kV. Bone however absorbs far more x-rays of low kV than high kV, so there is a relatively large difference in numbers of x-rays passing through the soft tissues compared to...
the bone using low kV, giving relatively high contrast. Increasing the kV allows relatively more x-rays to penetrate through the bone, and so affects both opacity and contrast. A low kV produces a high-contrast image but has low exposure latitude; therefore the exposure values are critical for a diagnostic image. A high kV results in low contrast, but has wider exposure latitude and the exact exposure levels are less critical. With digital radiography this can be more difficult to appreciate as the algorithms applied to the image during processing can override adjustments to kV and mA.

To obtain a radiograph with the same opacity as an original but with reduced contrast, halve the mAs and increase the kV by 15% (approximately 10 kV). Conversely, to increase contrast levels, double the mAs and reduce the kV by 15% to achieve the same opacity. Normally for good bone detail the kilovoltage should be less than 70 kV. Attenuation of the x-ray beam is heavily dependent on the atomic number of the tissues, and it is desirable that photoelectric absorption predominates. Increasing the kV also results in more forward scatter (see Grid below).

**X-ray film and image intensifying screens**

Although in many countries conventional x-ray film has been largely replaced by imaging plates, x-ray film is still in use and therefore merits discussion. Details of the structure of film, image intensifying screens and chemistry cannot be covered here, but are readily available in other radiographic textbooks. The principle however is important to an understanding of radiography. In simple terms a film consists of a cellulose acetate sheet coated with a light- (or x-ray) sensitive emulsion (a layer of complex silver halide crystals). When these crystals are subjected to x-rays (or light), they undergo partial chemical reduction, creating a latent image. Submersion in developer completes the chemical reduction. Subsequently when immersed in fixer, the reduced crystals are insoluble and remain on the film, but the unexposed crystals are dissolved, leaving the visible image. To make the system more sensitive, it is usual for the film to be placed in a cassette, which places an image intensifying screen on either side of the film. The screens fluoresce when stimulated by x-rays, and because the film is much more sensitive to light than x-rays, an image can be produced with a reduced x-ray exposure.

Important variables include the type of film being used and the compatibility of the screens, which intensify the image. It is important to match the spectral output of the screen with the spectral sensitivity of the film (see Appendix B). The large number of film and screen combinations available is beyond the scope of this book. The clinician should rely on a veterinary radiologist or knowledgeable sales person to help decide which film–screen combination is best suited to the x-ray machine and the practice, although Appendix B gives some guidelines. With a high-output x-ray machine (100 kV, 100 mAs), it is worthwhile investing in high-definition screens for use with single emulsion, relatively slow film, for distal extremity work. This gives excellent detail, but is unsuitable for low-output machines, because long exposure times result in loss of definition through movement blur. Rare earth screens are essential for obtaining high-quality images proximal to the carpus and tarsus. Old screens are like old horses, they collect scars and lose performance as they age, and therefore should be replaced on a regular basis in order to maintain the optimum level of performance. It is also important
that screens are cleaned regularly, to prevent the build-up of dust and extraneous materials within the cassette, which can result in white spots and lines on processed films.

**Film processing**

Good darkroom practice is an important consideration in the final quality of the radiograph but is often overlooked. Correct processing, whether manual or automatic, plays a major role. Standard darkroom procedures are available in any standard radiology text and are not covered here. There are however some processing errors that often cause film artefacts (see Appendix B) and thus affect interpretation. The following is a brief review of some of the basics principles that most often affect film quality and interpretation, especially when hand processing.

**Film fogging**

The most common darkroom problem whether using hand or automatic processing is fogging of the film either by light leaking into the darkroom, or improper darkroom lighting. Regardless of whether blue- or green-sensitive films are used, never rely on red or ruby bulbs as the source of darkroom lighting. For blue-sensitive film use a Wratten Series 6B filter with a 7–10 Watt bulb and for green-sensitive film use a Kodak GS1 filter with a 7–10 Watt bulb. In general the Kodak GS1 works with both blue- and green-sensitive film. The safelight should be a least 1 metre from the working area. There are two methods to check film for possible fogging:

1. In the darkroom place a sheet of film on the counter, then place an object on the film. Turn on the darkroom safelight and wait for approximately 30 seconds. This is the time it normally takes to place a film in a processor or on a hanger. Process the film as normal. If the darkroom is adequately dark and the safelight is suitable for the film, the film will be perfectly clear after developing. If the filter is incorrect or there is light leakage in the room, there will be fogging of the film around the object and the area covered by the object will be clear.

2. Expose a film in the cassette to an x-ray beam of 1–2 mAs and 40–50 kVp. This increases the sensitivity of the film. In the dark room place the exposed film on the counter and cover two thirds of the film with cardboard. Turn on the safelight for 30 seconds then move the cardboard over another third and continue the exposure for an additional 30 seconds. Process the film normally and compare the areas for fogging as described above.

**Processing**

There are three stages in the processing cycle that affect the final quality of the radiograph:

- Developer – converts exposed silver halide grains to metallic silver
- Fixer – converts unexposed, undeveloped silver halides into a form that can be removed from the emulsion and clear the film
- Washing – removes residual chemicals from film emulsion.

Important factors are the temperature and dilution of the chemicals and the time the film is in the developer and fixer.

[6]
1 Prepare the chemicals to the correct working dilution and agitate to ensure even mixing. Temperature is absolutely correlated with processing time. Deviation from time and temperature guidelines results in under- or over-development and loss of detail. At the optimal temperature of 20°C (68°F) developing time should be 5 minutes. A variation in time should be calculated for other temperatures. The temperature of the solutions should be checked after the rinse water has been on for at least 15 minutes. The darkroom should be kept at a constant temperature to assist in maintaining the solutions at the ideal temperature.

2 During development, fixing and washing, agitate the film several times to remove any air bubbles that cling to the emulsion. Air bubbles cause light or dark spots, or circular artefacts on the film, depending upon which solution the bubbles occurred in. Care must be taken to prevent films touching or being scraped by the hangers during agitation in order to prevent scratches of the wet (swollen) emulsion, or the development of kissing defects. A kissing defect occurs when two films cling to each other during any phase of the developing process, resulting in an area of incorrect processing. This can also occur when two films overlap each other in an automatic processor. When processing several films, all films should be loaded into hangers prior to being processed in order to maintain optimal timing.

3 Chemical levels must be high enough to cover the film in the hanger. Low chemical levels result in portions of the films being undeveloped which can result in loss of important information. To avoid chemical carry-over, in order to maintain developer and fixer strengths, fluid should drain from the film and hanger prior to placement in each solution, including the rinse tank. Loss of strength of developer results in underexposed film, while loss of fixer strength results in yellowing with age. Developer should be replenished after every session of processing to maintain it at correct working strength.

4 Developer deteriorates when not in use, therefore it must be changed regularly. If not kept covered the developer oxidizes. In either case this results in underdevelopment.

5 If it is essential to examine a wet film, wait until fixing is complete then quickly rinse the film and view it. Remember that wet films have swollen emulsion and detail is lost until the film is dry, when the halide crystals will have coalesced into a more definitive image!

6 The final wash is an important part of the processing cycle to remove residual chemicals from the emulsion. This prevents discolouration and fading of the image.

**Automatic processing**

The advantages of an automatic processor over manual processing are considerable. There is absolute consistency of processing, which enables a consistent estimate of exposure values, and results in marked improvement in film quality. There are also benefits of economy and speed. With automatic processing a dry film is available to read within 60–90 seconds compared with approximately 1 hour for manually processed film. Both manual and automatic processing require proper upkeep and maintenance of equipment to ensure diagnostic quality films. Regular maintenance of the processor is important as is making sure that processing fluids are fresh and in adequate
supply. The most common problems with an automatic processor occur when upkeep is not maintained.

**Radiographic practice**

In several parts of the following text, reference is made to an aluminium wedge filter (Figure 1.2). This is placed immediately in front of the x-ray tube, and absorbs a proportion of the x-rays. It allows the intensity of the beam to be reduced in specific areas. It is of particular value when radiographing parts of the horse that show a marked change in soft-tissue thickness from one side of the film to the other, e.g. the thoracolumbar spine or stifles, but is of less value when used with digital systems.

**Exposure chart**

It is advantageous to record the exposure settings used for each image, and gradually build an exposure chart. This should include a record of the size and age of the horse, the area radiographed, and the exposures and the film–screen combination or imaging plate used. This allows better and more consistent radiographs to be obtained, and also provides a basis for estimating the required exposures for animals of different sizes and ages. When creating this chart, it is important to maintain a constant FFD. A reduction in FFD increases the radiation reaching the screen by a square of the change in distance (necessitating a reduction in the exposure factors). An increase in distance has the opposite effect. Generally in equine radiography a FFD of 75–100 cm is used. Note that single emulsion film is particularly sensitive to changes in radiation dose; a slight change in FFD can therefore have a relatively big effect on exposure.

**Grids**

Most of the radiation during an exposure passes through the subject and exposes the film, or is absorbed by the tissues. Some radiation however is deflected (termed 'scatter') and this results in a low background exposure over the entire film, causing reduced film contrast. Good collimation of the primary beam reduces the amount of scatter at acquisition (Figures 2.1a–c). The effect of scatter can be reduced by placing a grid in front of the cassette to absorb the scattered radiation. As a rough guide, grids are generally only needed if the area being radiographed exceeds 11 cm in thickness. Thus equine extremities below
the carpus and tarsus usually do not require the use of a grid. Grids are generally not required for soft-tissue evaluation, and may be contraindicated in this situation. There are numerous types of grid, and advice on the best one for any specific situation is beyond the scope of this text. The disadvantages of a grid are that they increase the exposure required and produce lines on the films, which are sometimes found objectionable when reading the radiograph. If a focused grid is used, the x-ray beam must be perpendicular to the grid, centred on it, and at the correct FFD. When grids are of value, this is noted in the discussion of the projections described in the following text. Grids used with digital radiography have particular problems, and can cause serious image artefacts. The reader is advised to obtain specialist advice before acquiring grids for use with digital systems.

An alternative strategy is to use an air gap between the horse and the imaging plate rather than a grid. This can be helpful in areas surrounded by large muscle masses, for example the back or the pelvis, but will result in increased magnification of the area being radiographed.

Preparation and positioning

Preparation of the patient is essential to good radiography. Quiet and careful handling reduces movement, and sedation is often beneficial. Blinkers, blocking the horse's line of vision, may make it less apprehensive. Cotton wool earplugs or background music may make the horse less aware of the noise of the x-ray machine. Areas to be radiographed should be brushed to remove mud from the coat, which can produce confusing artefacts. For radiographs of the feet, the shoes normally need to be removed and the feet trimmed to remove loose horn and dirt.

It is important to ensure correct positioning of the horse before acquiring the radiograph. A small deviation in limb position can result in poor quality images with misleading information, making accurate interpretation difficult (Figure 1.3). In a well-positioned radiograph, the x-ray beam is perpendicular to the cassette to minimise image distortion.

Acquisition of additional images

It is important, if possible, to assess all the acquired images before terminating the examination. The images should be scrutinised for correct positioning and exposure, the presence of artefacts, and the identification of one or more potential lesions. Incorrect positioning may create an image which appears to have a lesion, but which disappears with correct positioning (Figures 1.4a and 1.4b, Figures 1w.4c–f; Figures 3.68b and 3.68c). The interpretation of the closeness of spinous processes is a good example. When on the margin of an image two spinous processes may appear separated because of a divergent x-ray beam, but if in the centre of the image clearly impinge (Figures 1w.5a and 1w.5b). Alternatively a lesion can be missed with inappropriate positioning, but become apparent on an image acquired with the limb correctly positioned (Figures 1.6a and 1.6b). Artefacts due to superimposition of normal structures, or the result of an opacity due to mud on the skin, can be confirmed by examination of the horse and an additional image can be acquired if necessary (Figure 1.7a, Figures 1w.7b–e). A lesion may be suspected from conventional images, but acquisition of additional images using additional projections may verify its presence and/or determine its
position more accurately (Figures 1w.8a–e). Ideally the presence of a lesion should be verified in more than one plane.

**Progression of lesions**

Images acquired at the time of onset of lameness may show advanced radiological abnormality despite the short duration of clinical signs (e.g. advanced degenerative joint disease of the centrodistal joint) (Figure 1w.9). Clearly the development of radiological changes preceded the onset of recognisable pain. Alternatively images acquired immediately after acute onset of lameness may show no detectable abnormality, but sequential examinations may reveal progression of the underlying disease process (Figure 1.10a–c). In some instances there will be resolution of a lesion over time (Figures 1w.11a–i), but some lesions remain radiographically evident after they cease to be of clinical significance (Figure 1w.12).
Figure 1.4(a) Caudocranial radiographic image of a stifle. Medial is to the left. The medial femorotibial joint space appears to be markedly narrowed. This was the result of inappropriate positioning during image acquisition. The limb to be examined should be positioned caudal to the contralateral limb. Compare with Figure 1.4(b).

Figure 1.4(b) Caudocranial radiographic image of the same stifle as Figure 1.4(a). Medial is to the left. The medial femorotibial joint space is normal.

Figure 1.6(a) Dorsopalmar radiographic image of a right metacarpophalangeal joint of a 4-year-old pony. Medial is to the left. The proximal sesamoid bones are superimposed over the metacarpophalangeal joint space.

Figure 1.6(b) Dorsal 10° proximal-palmarodistal oblique image of the same metacarpophalangeal joint as in Figure 1.6(a). Medial is to the left. The proximal sesamoid bones are now projected proximal to the metacarpophalangeal joint space which appears narrower medially, consistent with degenerative joint disease. Narrowing of a joint space should ideally be confirmed by being seen on more than one image.
Radiation safety

Radiation safety, i.e. ensuring that personnel around the horse do not receive doses of radiation, is extremely important. There are codes of practice available in different countries, but the basic principles can be summarised as follows:

1. Keep the number of people present when radiographing a horse to the absolute minimum required for its safe handling.
2. Use appropriate restraint of the horse to keep it still during exposures (so that repeat exposure to radiation is not necessary). Sedation may be required.
3. Use cassette holders whenever possible. Because radiation intensity follows the inverse square law, increasing distance from the source is an important safety factor. Certain views, where ‘patient tolerance’ is low, may prompt the hand holding of cassettes. This may be justified if it reduces the repetition of radiographs or prevents the horse panicking. If it is essential to hand hold a cassette, then large cassettes should be used, with the x-ray beam well collimated, and the holder’s gloved hands as far from the primary x-ray beam as possible.
4. The primary x-ray beam should be well collimated, and a light beam diaphragm used to enable maximum collimation. No part of any attending person, even if covered with protective clothing, should be placed in the primary beam. Protective lead clothing protects from scattered radiation only, not the primary beam. Remember that the primary beam continues through the patient and cassette, and personnel standing on the opposite side of the patient are at risk.

Figure 1.7(a) Dorsoproximal-palmarodistal oblique image of a right front foot. Lateral is to the right. There is a radiolucent line in the lateral palmar process of the distal phalanx. This could potentially be misdiagnosed as a fracture but note that the line extends just proximal to the proximal margin of the bone and is the result of inadequate packing during image acquisition.

Figure 1.10(a) Dorsolateral-palmaromedial oblique (flexed) image of the right front foot of a 9-year-old pleasure horse with sudden-onset severe right forelimb lameness the previous day while misbehaving when loading to travel. There is a narrow radiolucent line through the lateral palmar process of the distal phalanx (arrows) representing a fracture.
All personnel who must remain present during radiography must wear protective gowns, and if near the primary beam should also wear gloves or similar hand and arm protection, and a thyroid protector.

All personnel working with and around x-ray machines should be monitored using a film badge or dosimeter system.

Walls of a room or stable provide a primary barrier but be aware that although dense breeze block will stop the primary beam, a wooden partition will not.

N.B. Digital processing of images will marginally reduce the radiation dose, but this is not a reason to ignore normal radiation safety precautions. In practice the use of digital imaging often increases the number of images acquired, and increases the need for vigilance regarding radiation safety.

Examination for purchase

Because of the general acceptance of this text world-wide, it is impossible to write a comprehensive section that covers all areas of the radiographic examination included as part of a pre-purchase examination in all countries. When making such an examination, it is necessary to take into account many variable factors such as the breed and intended use, as well as considering both the country of origin and the country to which an animal is being sold. This carries many different legal implications and is therefore well beyond a text that is limited to radiology. Guidelines regarding this have been published, and the reader is referred to ‘Further reading’.

As a general guide, the radiographic portion of a pre-purchase examination must first take into account the general health, age and condition of the...
horse. It is important that the previous and intended use(s) of the horse are considered, with special emphasis on conditions prevalent in the relevant breed or use of the horse. The radiographic evaluation should follow the physical examination, to include areas that might be expected to face the greatest stress in the performance of the expected use, and to investigate potentially significant findings discovered during the physical examination. It is essential that if adequate interpretation is to be made, film quality must be good, and an adequate number of views obtained to evaluate the specific area(s) of concern. No simple guide can be given for this, except to say that as a general rule there must be at least two views of a suspected lesion, and it is clinically better to have too many views than too few, bearing in mind the overriding importance of radiation safety. When imaging apparently normal joints (such as fetlock or hock) it is generally necessary to obtain dorsopalmar (dorsoplantar), lateromedial and two oblique views of each joint. If the horse is to be insured, the insurance company may have specific minimum requirements for views to be obtained. Sales companies for Thoroughbred yearlings and racehorses in training frequently specify what views of which joints are required. Some countries have a designated set of radiographs that should be obtained as part of a pre-purchase examination. If a client is purchasing a horse abroad they should be advised that the radiographs obtained may not be the same as in their own country, where additional views may be considered necessary to provide a comprehensive examination.

A report on pre-purchase radiographs should begin with a clear identification of the animal examined. This must be followed by sections on each area examined, stating the views obtained and giving a clear and concise description of the radiological findings, starting with the most significant finding. Finally an opinion on the potential significance of any abnormalities should be provided, relative to the intended use of the horse. If for any reason the radiographic study is limited, this should be clearly stated in a disclaimer. For example, ‘The owner refused to allow sedation and therefore the examination of the foot is incomplete’; or, ‘The study is compromised by the presence of shoes which could not be removed due to permission being refused’. In extensive reports it is useful to finish with a clear summary of significant findings relevant to the potential use of the horse if purchased.

**Records and labelling**

Radiographic images and reports are part of medical records, and should be stored carefully with patient records. In the United States both radiographs and radiographic reports must be kept for legal reasons for a minimum of 7 years, and this is a good principle to apply. The quality of the films/images will reflect on the quality of the practice, and this becomes particularly important when films may be viewed by other practitioners, for example in a pre-purchase examination. All films and digital images should be clearly identified with permanent labels at the time of acquisition.

With the increasing use of radiography, and the rise in litigation involving veterinarians worldwide, it is essential that radiographs are carefully labelled. This should be done digitally or photographically on the film, either by the use of one of the special tapes produced for this purpose, attached to
the cassette when the film is exposed, or by a labelling light-box system in the darkroom. Labels should include as a minimum:

1. The identity of the horse and owner.
2. The limb radiographed.
3. The date.
4. Lateral or medial markers where relevant should be placed on the cassette.
5. The identity of the veterinary practice.
6. The view employed (assuming this cannot be determined from the radiograph).

Digital systems may produce such labelling automatically, and the technician acquiring the images should ensure that correct information is recorded.

It is essential that a complete examination is carried out, with an adequate number of views of each area involved. The exposures must be correct to demonstrate any lesions present, the radiographs must be of diagnostic quality, and images should include all of the area being examined (e.g., images of hock joints frequently miss the proximal aspect of the calcaneus, or the tarsometatarsal joint). An inadequate examination may be at best inconclusive and at worst totally misleading. Such examinations in the hands of the legal profession may prove devastating!

PRINCIPLES OF RADIOGRAPHIC INTERPRETATION: RADIOLOGY

It is important to read radiographic films when they are dry. The emulsion swells when wet and detail cannot be appreciated on wet films.

It is helpful if radiographs are always viewed using the same orientation, i.e., with the horse facing to the viewer’s left, medial on the left, and when appropriate the left side on the right. This aids interpretation, as only one image need be remembered for each area radiographed. (This varies slightly from the convention that any film should be viewed as if the examiner was looking at the patient face on, e.g., the left forelimb is viewed with medial to the left, and the right forelimb with medial to the right.) The number of views required for any area varies, and is mentioned in the text. It is important to obtain an adequate number of views to ensure that no lesion is missed, and an attempt to compromise with fewer views is a false economy. The use of ‘special’ views, e.g., oblique and ‘skyline’ views, of suspected lesions can be very rewarding.

Adequate radiological interpretation is dependent on complete and systematic evaluation of all of the information that is found on the image. Films should be viewed on a viewing box, in a room with subdued light. This optimises the ability of the reader to differentiate structures and to obtain the maximum information from a film. The darker the film, the more important it becomes that the conditions under which it is read are ideal.

Initially the film should be evaluated from a distance of several feet before viewing closely, in order to get an overall impression before concentrating on details. Areas of diffuse, subtle change in radiopacity are usually more readily identified from a distance than close up. Masking the light around the edge of the radiograph also improves the ability to read a film, as do high-intensity illumination devices.
Digital images should be viewed on high-definition flat screens, again in a room with subdued light. As with film, it is helpful to mask the image to remove light areas around the point of interest. In many systems it is then possible to select the area of most relevance, and to adjust contrast and brightness of the region concerned to aid evaluation of a wide range of tissue densities. Most systems also allow for enlargement of the whole image, or of specific regions of interest (see Chapter 2).

With film or digital images, start by assessing the image itself:

- Is the quality of the image adequate for interpretation?
- Is the view correctly positioned to allow correct interpretation?
- Are there any processing or other artefacts (e.g. mud on the horse) that will influence interpretation?

Then move on to assess the area radiographed:

- Is there any soft-tissue swelling?
- Is there any alteration of opacity of the soft tissues?
- What is the approximate age of the patient?

Finally look at the outline of the bones and their detailed internal structure:

- If an ‘abnormality’ is identified, ensure that it is real – can it be seen on another view? Can it be explained by positioning or overlap of other bones or soft-tissue structures? Is it a variation rather than an abnormality, e.g. the position and shape of a nutrient foramen can vary considerably. Could a radiolucent zone be explained by introduction of air during a previously performed local analgesic technique (Figure 1.13a and b). Intra-articular gas appears as a semicircular or more diffuse radiolucent area, often in the proximal

![Figure 1.13(a)](image)

*Dorsolateral-palmaromedial oblique image of the distal metacarpal region and metacarpophalangeal joint of a mature horse. There are radiolucent areas superimposed over the third metacarpal bone. These gas shadows are the result of inadvertent introduction of air into the metacarpophalangeal joint while performing intra-articular analgesia. Such lucent areas may persist for up to 48 hours. Note also the periarticular osteophyte formation on the dorsoproximal medial aspect of the proximal phalanx consistent with degenerative joint disease. There are also multiple radiolucent lines in the lateral proximal sesamoid bone.*
part of a joint, whereas extra-articular gas appears as a linear radiolucency. These lucencies may persist for up to 48 hours after injection

- Would additional views aid or complete adequate evaluation?
- If it is a true radiographic lesion, describe it in radiological terms.

In this process of description it is often possible to determine if it is an active or inactive process. In general, terms like smooth, regular and well marginated (defined) lead towards a conclusion of normal, benign or long-standing lesions. Terms such as roughened, irregular, sharp, poorly demarcated or destructive, lead to a conclusion of active disease. If the process is considered to be pathological, then think what pathological process could cause this change and then consider what diseases could cause this type of pathology.

If images are obtained to confirm the presence of a specific disease or disease process and are not completely evaluated, the severity of the condition, complications of the process or other concurrent lesions may be overlooked. Thus to read radiographs successfully, it is important to relate the changes seen to known behaviour of the tissues under consideration, rather than relating the radiographic appearance to a clinical condition seen before. The latter method relies heavily on experience and does not allow interpretation of changes that have not been previously encountered. It is important to remember that each radiograph can only represent a fraction of a second in the life of the patient, and the development of a disease process. It is a static image of a dynamic process. When a radiograph is read, all the changes from the normal should be considered and used to build up an impression that can then be related to disease processes known to occur in the region.

Figure 1.13(b) Dorsomedial-palmarolateral oblique image of the same limb as Figure 1.13(a). There are discrete radiolucent areas (arrows) in the soft tissues distal to the distal aspect of the second metacarpal bone representing air in the palmar recess of the metacarpophalangeal joint.

[17]
For accurate interpretation it is important to take into account factors such as the period of time for which the clinical signs have been present, the age, sex and breed of the patient, and the validity of the history and possible complicating factors. A working diagnosis can then be formed, which will complement any laboratory findings and other imaging techniques, and help to confirm a clinical diagnosis. There is no substitute for a good clinical history and examination, and radiographs should only be used as an aid to the clinical diagnosis.

It is beneficial to have bone specimens available when reading radiographs, particularly oblique images. An anatomy book and a library of normal radiographs of each anatomical area at different ages are invaluable. If problems are encountered in evaluating an area, it is often helpful to obtain a similar radiograph of the contralateral limb for comparison, thus providing a perfect age-, sex- and breed-matched radiograph. Remember that, in the neonate, some structures are not ossified and therefore cannot be seen. More confusing is the appearance of partially ossified structures (e.g. incompletely ossified subchondral tissues have an irregular opacity, which may seem similar to the radiographic appearance of infection). The normal radiographic appearance of the structures of immature animals is therefore described in each chapter. Digital images are easily transferred electronically, therefore it is always easy to get the advice of an expert if there are queries concerning interpretation.

Radiographs are only one part of a jigsaw puzzle and may be used for several purposes:

- To confirm, refute or suggest a diagnosis
- To give information on progression and severity of a condition, and aid formation of a prognosis
- To add information regarding size, shape, position, alignment and possibly duration of a lesion.

When reading a radiograph the result must be fitted into the general picture presented to the clinician. It is one aid to diagnosis that the clinician has available. In some cases special views or contrast studies may provide valuable additional information. There are many other complementary imaging techniques (e.g. ultrasonography, nuclear scintigraphy, computed tomography and magnetic resonance imaging) and other sources of clinical information that are available. The radiograph is an aid to diagnosis and not the ultimate diagnosis in itself.

One of the most difficult questions to answer is how long a lesion has been present. This is often of importance, but can seldom be answered with any degree of certainty. Minimum times for certain lesions to develop can be estimated, but the time for which a lesion has been present often remains uncertain. The following pointers may be of value:

- Osteophyte formation of any type is not normally visible, even under optimum conditions, in less than 3 weeks
- Treatment after injury may delay osteophyte formation
- Incomplete or fissure fractures may take up to 2 weeks to become visible
- Active bone changes are characterised by lesions with irregular or fuzzy margins, which may be less opaque than the parent bone
- Inactive bone changes are generally smooth, regular and uniformly opaque
Large productive changes may take months to form and become smooth in outline.

An old inactive bone lesion may not indicate current disease, although it may be present in the same region as a current problem.

Bone models according to the stress applied to it (Wolff’s law). Non-stressed bone does not model.

Scars in bone, as in any other tissue, do not model.

It can be difficult to predict the progression of an injury accurately based purely on one set of radiographs. Sequential radiographs acquired at weekly intervals may demonstrate dramatic changes which may have a major influence on prognosis (Figures 1.14a and 1.14b). Do not be tempted to over interpret radiographs acquired at the time of an acute injury (Figures 1w.14c and 1w.14d).

It should be noted that the terms remodel and model are frequently used incorrectly in radiology (see Appendix C: Glossary). In this text, the term remodel is frequently employed because of its common usage. Modelling is, however, a more correct term, compatible with changes detectable radiographically (and histologically).
CHAPTER I
General principles

RADIOLOGICAL APPEARANCE OF PHYSIOLOGICAL CHANGES AND SOME COMMON PATHOLOGICAL LESIONS

Bone changes

The basic ability of bone to respond to stimuli is affected by various factors, such as diet, disease and the physiological state of other organs such as the lungs, kidneys and gastrointestinal tract.

It is important to remember that the normal bone status varies throughout life. During the period of skeletal growth, there is increased bone formation relative to resorption. The skeleton of the young individual lacks density and is more pliable (35% mineral to 65% matrix and cells). As the individual matures, the density gradually increases (approaching 65% mineral and 35% matrix and cells). With advancing age the bone–mineral balance changes towards decreased formation and increased resorption.

Although it is common to think of bone as being largely calcium, the mineral content of bone is roughly 35% calcium, 17% phosphorus and 12% copper and other minerals. Radiologically it is not possible to detect a decrease in mineralisation of less than approximately 30% of the total mineral content, and therefore changes in bone mineralisation may be undetectable radiographically early in a disease process. Diagnostic ultrasonography may be helpful in early detection of some bony changes affecting surfaces of bones, e.g. periosteal new bone formation.

It is important to remember that some changes reflect past history, rather than the response to current stimuli; thus some radiographic lesions may no longer have clinical significance, but persist as incidental findings.

Wolff’s law states that bone models according to the stresses placed on it, and modelling is dependent upon bone function and the distribution of the load. Forces are applied to bone at the sites of attachment of ligaments and tendons or through the joints. Application of a load may deform the part concerned. Deformity is dependent upon the degree of the stress and the number of loading cycles.

When evaluating radiographs it should be remembered that bone is a living dynamic tissue that can only respond in a finite predictable way to an infinite number of outside stimuli or insults.

Demineralisation of bone

GENERALISED DEMINERALISATION

Generalised demineralisation or osteoporosis may be recognised by: thinning of the cortices; coarser, more obvious trabecular pattern; apparent radiographic overexposure due to reduced bone density (check the FFD, exposure values and processing technique). With digital imaging, exposure differences are more difficult to detect, and evaluation of the cortices and the trabecular pattern becomes more important. Generalised demineralisation (Figure 1.15) may result from a mobilisation of minerals because of a need elsewhere in the body, e.g. in pregnancy, dietary inadequacy or metabolic imbalance (e.g. secondary nutritional hyperparathyroidism), or renal disease. Alternatively the lack of mineral may indicate that the patient is very young or very old.

[20]
localised demineralisation

Loss of mineral in a single limb indicates a process limited to that area, e.g. the loss of mineral in one limb may relate to disuse osteopenia (Figures 1.16a and 1w.16b). Mineral is lost due to muscular inactivity and/or reduction in weight bearing. It should be compared with the contralateral limb if a generalised disease might be implicated.

focal demineralisation

Focal loss of bone (Figure 1.17) may indicate the presence of infection, neoplastic invasion, or replacement of bone by fibrous tissue as a result of a previous disease process (this may be considered to be equivalent to a scar in bone).
It is also seen:
- As an osteochondral defect in osteochondrosis (although this may actually represent delayed mineralisation rather than demineralisation)
- In osseous cyst-like lesions
- As subchondral bone loss in degenerative joint disease
- In association with vascular abnormalities
- Along fracture lines.

It may also result from continuous pressure on bone, as in chronic proliferative synovitis or other space-occupying masses.

**Increased bone production**

Increased bone production may result in increased bone density and thus radiopacity.

A generalised increase in bone density may be due to fluorine poisoning or a hereditary disease such as osteopetrosis. In some species, but as far as is known not the horse, mineral deposition could indicate hypervitaminosis A.

**Cortical thickening**

Wolff’s law states that bone models according to the stresses placed on it, and is dependent on its function and the distribution of the load. Cortical thickness, particularly of the third metacarpal and metatarsal bones,
changes from a young, skeletally immature, untrained horse to a mature trained horse. The dorsal cortex becomes significantly thicker than the palmar cortex. If a horse has a marked conformational abnormality, such as ‘off set knees’, the distal limb bones will model accordingly, resulting in increased thickness of the cortices of the regions of the bones carrying increased load.

**FOCAL NEW BONE FORMATION**

*Osteophytes* are spurs of bone at the margin of a joint. Osteophyte formation occurs in response to various stimuli. The time taken for an osteophyte to develop after a stimulus varies between individuals and depends upon the inciting cause. It may take as little as 2 weeks, or may take several weeks. Osteophyte formation with uniform opacity and a smooth outline is likely to be longstanding and inactive. More lucent osteophyte formation, or a formation with a more lucent tip, is likely to be actively developing. *Periarticular osteophytes* may be associated with intra-articular pathology, and develop at the margins of articular cartilage and periarticular bone (Figure 1.18). They also develop as a consequence of joint instability.

*Entheseophytes* are spurs of bone that develop where tendons, ligaments or joint capsules attach to bone. They represent the response of bone to stress applied through these structures, whether it is tearing of a portion of a ligament, chronic stress applied by a tendon, capsular traction, or chronic capsular distension. It may be difficult to differentiate between osteophytes and enthesophytes in some areas.

---

*Figure 1.18* Caudocranial radiographic image of a stifle of a 14-year-old Welsh Section D Cob. Medial is to the left. There is a moderately sized osteophyte on the proximomedial aspect of the tibia, reflecting osteoarthritis. Lameness was improved by intra-articular analgesia of the femorotibial and femoropatellar joints. Arthroscopic evaluation revealed a tear of the medial meniscus, severe fibrillation of the cranial ligament of the medial meniscus and abnormalities of the articular cartilage.
Periosteal and endosteal new bone formation result from inflammation of the periosteum or endosteum. This may result from a fracture (the callus forming endosteal and periosteal new bone), trauma, infection, abnormal stress at a soft tissue attachment, or tumour formation.

Sclerosis

Sclerosis is a potentially misleading term. Its true pathological definition is increased hardness of a tissue, a phenomenon that cannot be determined radiologically. It is a term adopted by radiologists to describe localised increased opacity of the bone due to increased bone mass within existing bone. It is most readily recognized in trabecular bone, and occurs in response to several stimuli including:

- Stress (e.g. increased thickness and/or opacity of the subchondral bone in degenerative joint disease)
- An attempt to wall off infection (e.g. in the medullary cavity adjacent to an area of osteomyelitis; in response to osteitis of cortical bone adjacent to the site of infection; adjacent to sequestration)
- To support or protect a weakened area (e.g. a rim of increased opacity surrounding an osseous cyst-like lesion).

Bone lesions

Physitis (epiphysitis)

Physitis (or physeal dysplasia) is the term that should be used to describe abnormal widening and bony irregularity at the epiphyseal and metaphyseal margins of the growth plate in skeletally immature horses. The metaphysis of the bone is broadened and asymmetrical. There is increased opacity of the metaphysis adjacent to the physis, which may be more irregular in appearance than normal, with parallel radiolucent lines reflecting retained cartilage cones. The cortices of the metaphysis may be abnormally thick. Soft-tissue swelling over the area of involvement is usually present, and there may be an associated angular limb deformity. These changes are secondary either to rapid cartilage production or to defects in mineralisation and/or ossification to produce the primary spongiosa.

Although any physis may be involved in this process, physitis is most commonly associated with the distal radial (see Figure 7.23) and distal metacarpal/metatarsal physes. Focal osteochondral defects have been noted histologically and result from repeated haemorrhage and/or microfractures that interfere with the blood supply to the mineralising cartilage. Osteochondrosis-like defects have also been described.

Widened metaphyseal and physeal bone that is produced during the acute stage of the disease may persist throughout life, resulting in an irregular or flared appearance at the location of the physeal scar, although in many cases, considerable modelling towards normality occurs.

Neoplasia

Primary tumours and metastatic malignancy of the long bones of horses are rare. The majority of tumours that involve bone occur in the skull (see Chapter 11, ‘Significant findings – Other causes of opacity of the maxillary
sinus’ and ‘Significant findings – Tumours’) or occasionally the spine (see Chapter 12, ‘Cervical vertebrae – Neoplasia’ and ‘Thoracolumbar vertebrae – Neoplasia’). Tumours result in space-occupying lesions that may be radiopaque or radiolucent. Adjacent bone may be distorted in outline, and there may be associated new bone production. It is frequently not possible to differentiate specific tumour types by their radiological appearance. A malignant tumour may be similar radiographically to the result of infection, and differentiation is based on history, clinical signs, laboratory tests and biopsy.

**Osteitis and osteomyelitis**

Osteitis is inflammation of bone, and osteomyelitis is inflammation of cortical bone and its myeloid cavity. In bones that do not have a myeloid cavity (e.g. the distal phalanx), it is not appropriate to use the term osteomyelitis. Osteitis is usually the result of trauma or inflammation in adjacent soft tissues. It is characterised by new bone formation and sometimes bone resorption. Differentiation should be made between aseptic osteitis and infectious osteitis (see below).

**Infectious osteitis and infectious osteomyelitis**

Infectious osteitis (inflammation of bone due to infection) and infectious osteomyelitis (inflammation of the bone involving the myeloid cavity) are common in the horse. In an adult, infectious osteitis is more common and is usually seen at a single site, often related to trauma such as wire cuts or puncture wounds. The hallmarks of infection are:
- Soft-tissue swelling with bone destruction and new bone formation
- An attempt to wall off infection resulting in radiopaque bone forming adjacent to the area of bone infection and destruction
- Infection of bone may result in the formation of a sequestrum (a piece of dead, initially radiopaque bone) surrounded by an involucrum (an area of lucent granulation tissue) (see Figures 6.23b and 6.23c). A radiolucent tract may be visible extending from the infected area (a sinus)
- The distal phalanx, distal sesamoid (navicular) bone and skull show a slightly different reaction to infection. In these bones, infection tends to cause destruction of bone with little evidence of new bone formation
- In the foal, osteomyelitis is more common and may occur simultaneously at several sites, often extending into adjacent joints. The converse is also true, and septic arthritis commonly extends into adjacent bone causing an osteomyelitis. Osteomyelitis in the foal tends to be very destructive and there is usually very little response by the bone to wall off the infection.

A useful classification of infection of bone and joints has been devised by Firth (see below, ‘Infectious arthritis’).

**Hypertrophic osteopathy**

Hypertrophic osteopathy was formerly known as Marie’s disease, hypertrophic pulmonary osteoarthropathy or hypertrophic osteoarthropathy. It is now termed hypertrophic osteopathy because it has been shown that pulmonary involvement is not a prerequisite for the development of the disease, as was once thought, although pulmonary lesions may be present. Hypertrophic osteopathy principally affects the metaphyses and diaphyses of the long bones, while sparing the joints. The disease is typified by periosteal new bone that often appears to be forming perpendicular to the cortices of the bone...
and is irregular in outline in the acute stage (Figures 1.19a and 1w.19b). In the early stages, soft exposures must be used to avoid overexposure of this relatively lucent new bone. Later the margins of the new bone become more opaque and smoother, and the appearance of the original cortex of the bone becomes less clear. The bony lesions develop secondarily to a primary lesion, usually in the thorax or occasionally the abdomen, such as a tumour, an abscess or diffuse granulomatous disease. The cause and distribution of the bony lesions are not understood, however, the bone changes may regress and remodel if the primary disease can be identified and successfully treated.

*Enostosis-like lesions and other circumscribed opacities*

An enostosis is defined as bone developing within the medullary cavity or on the endosteum, resulting in a region of increased radiopacity. In the horse enostosis-like lesions have been described as focal or multifocal, intramedullary sclerosis. They are usually in the diaphyseal region of long bones, near the nutrient foramen, often developing on the endosteal surface of the bone. The most common sites are the tibia, radius, humerus and third metacarpal and metatarsal bones (Figures 1.20, 6w.24a and b, and 10w.40). The aetiology and clinical significance of the lesions are unknown. However, they may be associated with lameness, which usually resolves with rest. Enostosis-like lesions are frequently associated with focal increased radiopharmaceutical

*Figure 1.19(a)* Dorsolateral-palmaromedial oblique image of the left metacarpophalangeal joint of a 10-year-old Thoroughbred mare. There is palisading new bone on the distal dorsal aspect of the third metacarpal bone and the dorsal and palmar aspects of the proximal phalanx, with overlying soft tissue swelling. The metacarpophalangeal and proximal interphalangeal joints are not involved. The areas of new bone formation were painful on palpation and the mare moved stiffly. All four limbs were involved. Diagnosis: hypertrophic osteopathy.
uptake, whether or not they are causing lameness. Such focal radiopacities should be differentiated from endosteal callus secondary to a fatigue or stress fracture. Small focal opacities in the proximal metaphyseal (Figure 10w.41) or diaphyseal region of the tibia have been recognised. Their aetiology and clinical significance are unknown.

Heterotopic ossification

Heterotopic ossification, also known as myositis ossificans, is a well-recognised condition in humans, typified by the development of bone at sites where bone does not normally exist. The aetiology is unknown. It may occur
after muscle trauma, but can also develop after brain or spinal cord injury, burns and surgery. It is generally associated with regional pain. It occurs rarely in the horse (Figure 8w.20a and b).

Fractures

A fracture is a discontinuity of the bone seen radiologically as a lucent line or lines. Radiography is performed to establish the type, severity and degree of displacement of the fracture, and to assess the damage to adjacent joints and surrounding soft tissues. Later radiographs may be obtained to assess the degree of reduction achieved and to monitor healing. In order to establish the presence of a fracture, at least two projections, preferably obtained at right angles to each other, are essential. Many more views may be necessary to establish the exact configuration of the fracture.

Fatigue (stress) fractures and other non-displaced and/or incomplete fractures can be extremely difficult to detect in the acute stage. Mach lines due to edge enhancement should not be confused with fractures. These are particularly evident with certain digital imaging software. For best detection of a fracture, the x-ray beam must be parallel to the plane of the fracture, and thus detection may necessitate obtaining many views at 5° angles to each other. Two radiolucent lines often represent a single complete fracture, which traverses through two cortices, e.g. dorsal and palmar, and should not be confused with two fractures. During the normal healing process there is osteoclasia along the fracture line within 5–10 days, resulting in apparent broadening of the lucent fracture line (see Figures 1.10a–c, 6.29a and 6.29b). Thus a fracture line that was not readily apparent in the initial radiographs may be detected on follow-up films obtained 5–10 days later. In the acute stage, nuclear scintigraphy may be a better method of detecting the presence of an incomplete fracture or a fatigue fracture. Some fractures are never visible radiographically, despite there being strong evidence of a fracture from nuclear scintigraphic evaluation. Some radiographically detectable stress (fatigue) fractures may be preceded by the development of increased opacity before the fracture becomes apparent.

A fracture should be evaluated to establish whether it is unicortical or bicortical, simple, multiple or comminuted, whether there is articular involvement, the degree of displacement of the fracture fragments and to identify any concurrent pathology which may adversely influence the prognosis.

Fractures involving the physis of a bone may be classified according to Salter-Harris, based upon the configuration and relationship of the fracture plane to the metaphyseal growth plate. Salter-Harris classifies the fractures as follows (Figure 1.21):

Type I Fracture through the zone of hypertrophied cells without involvement of the adjacent epiphysis or metaphysis

Type II Fracture through the physis across part of the width of the bone and through the metaphysis, leaving a segment of the metaphysis attached to the epiphysis

Type III Fracture through the physis across part of the width of the bone and through the epiphysis, entering the joint

Type IV Fracture across the epiphysis, physis and a portion of the metaphysis, perpendicular to the plane of the physi

Type V Compression fracture of the physis with minimal displacement
Although this classification has now been further extended, we feel that the above classification is adequate for practical clinical purposes.

Fracture healing should be monitored radiographically to determine the progression of healing. The time interval between re-examinations depends on the severity of the fracture, the type of repair and the clinical reassessment of the patient. Following initial mineral resorption along the fracture line, and formation of a fibrous callus, calcified periosteal and endosteal callus develops. The amount and quality of callus that develops depends upon the degree of stability at the fracture site (Figure 1.22) and the presence or absence of concurrent infection. Endosteal callus is more difficult to see radiographically, but ultimately results in disappearance of the fracture line. Stability of the fracture may develop long before the fracture line disappears radiographically. Some bones (e.g. the proximal and distal sesamoid bones and the accessory carpal bone) tend to heal by fibrous union, resulting in a persistent lucent line. The rate of healing varies and is dependent on many factors, including the age of the horse, its nutritional and metabolic status, the degree of stability of the fracture, the site of the fracture, the presence or absence of periosteum, the blood supply to the bone, and the presence or absence of infection. Infection is likely to be progressive and impair osseous union unless there is stability at the fracture site.

If a fracture is repaired by internal fixation, and there is adequate stability at the fracture site, healing should be predominantly by primary union, with minimal periosteal callus. Instability at a fracture site results in secondary union by the production of periosteal callus (Figure 1.23), or may result in fibrous union or malunion of the fracture.

If a fracture has been repaired by internal fixation, the implants and surrounding bone should be examined carefully on follow-up radiographs. The development of localised lucent zones around the implants indicates loosening of the implant, or infection, and it may be necessary to remove one or more selected portions of the implant. Diagnostic ultrasonography may be helpful in early detection of osteomyelitis in some cases, e.g. detection of fluid around a screw head.
Figure 1.22 Craniocaudal image of a radius of a 6-year-old Irish Sports Horse obtained 4.5 weeks after a kick injury. Lameness was not apparent until 3 days after the injury and progressively deteriorated over the following week. Medial is to the left. There is marked endosteal reaction of the medial cortex of the mid-diaphyseal region (arrowheads), extending proximal and distal to an ill-defined radiolucent line through the cortex, an incomplete fracture (black arrow). There is smoothly marginated periosteal new bone, callus, extending proximal and distal to the radiolucent line (white arrows) and mild overlying soft tissue swelling.

Figure 1.23 Dorsopalmar image of the distal metacarpal region of a 3-year-old Thoroughbred racehorse with sudden onset of left forelimb lameness 6 weeks previously. Medial is to the left. There is an approximately horizontal radiolucent line traversing the distal metaphyseal region, representing a complete fracture and very extensive irregularly marginated periosteal callus extending along the medial and lateral cortices, reflecting a secondary healing response to an unstable fracture.
If implants are removed when there is stability at the fracture site, radiolucent tracts will persist for 8–12 weeks where the implants passed through the bone. These tracts may act as stress points until adequate remineralisation has occurred, and are potential sites for fracture to recur. Such stress points, of course, are also present with the implants in place.

Whether a fracture is treated conservatively or surgically, once initial mineral resorption along the fracture line has occurred, there should be progressive narrowing of the fracture line or lines, and they should gradually disappear. Healing may be complete within 6–12 weeks, but some fractures take considerably longer. A horse may be sound and be able to withstand work, despite the persistence of a radiolucent fracture line and some fractures heal more completely once careful controlled walking exercise is initiated. In some locations (e.g. third metacarpal condylar fractures) the long-term persistence of a lucent line is commonly associated with recurrent lameness. If a fracture line persists beyond 6 months it can be considered to be a delayed union. There may be increased opacity of the bone adjacent to the fracture line, and the ends of the bone may become slightly flared (Figure 1.24).
Although delayed union is not uncommon in the horse, non-union (complete failure of osseous union after 12 months) is rare, except in the areas previously mentioned where healing is frequently by fibrous union. If there is apparent healing by fibrous union, it is usually impossible to state when the original fracture occurred. Fractures of the distal sesamoid (navicular) bone usually heal by fibrous union, and frequently lucent zones develop adjacent to the fracture line. These lucent zones are indicative of a fracture of at least 6–8 weeks’ duration.

**Joint lesions**

**Swelling**

Soft-tissue swelling in and around joints may be classified as shown below.

**INTRA-ARTICULAR SWELLING**

With intra-articular swelling the joint capsule is distended and in a non-weight-bearing patient there may be a widened joint space. In some locations (e.g. the carpus) the normal dorsal lucent fat pad may disappear due to compression. Joint distension is usually associated with inflammation and may be septic or aseptic. Softly exposed radiographs may demonstrate distended joints away from weight bearing parts of the joint. If several joints are involved in a neonatal animal, septic arthritis should be considered. If several joints are involved in older animals, immune-mediated disease should be considered, especially if the occurrence is cyclical in nature.

**PERIARTICULAR SWELLING**

Periarticular swelling does not involve the joint space, but may involve the joint capsule as is seen in sprains. Periarticular swelling may also be caused by conditions that are more obvious on examination of the patient than on the radiograph, such as wire cuts, puncture wounds and external trauma. With cuts and wounds, gas may be evident within the soft-tissue swelling. Generalised periarticular swelling may result in the inability to differentiate between intra-articular and extra-articular fluid accumulation. The inability to differentiate may result from massive swelling or the loss of soft-tissue fat which is normally found in the pericapsular, peritendonous and periligamentous areas.

**Trauma**

Joint trauma may be classified as follows:

**Sprain**

Joint sprain is the wrenching of a joint with partial rupture or other injury of its attachments, but without luxation of bones. There is usually rapid swelling, heat and pain. Sprains must be differentiated from fissure fractures and other causes of acute joint swelling. Sprains may be classified as shown in Table 1.1.
If ligament rupture or avulsion is suspected, stressed radiographs (Figures 1.25a and 1.25b; see ‘Subluxation and luxation’, below) should be obtained to assess the integrity of the joint and the possibility of subluxation. Ultrasonography may yield additional information.
Luxation is the complete loss of contact between the articular surfaces of a joint. Subluxation of a joint is partial loss of contact between joint surfaces, and may be intermittent. Luxation and subluxation in the horse are usually the result of trauma, although congenital luxation of the patella occurs rarely. Subluxation of the proximal interphalangeal joint (Figure 4.9) may develop without an obvious cause, but may also occur secondary to injury of the oblique or straight sesamoidean ligaments. Luxation is usually easily identified radiographically (Figure 8.23), but multiple radiographic views are required in order to assess whether or not there is a concurrent fracture that may adversely influence the prognosis. If luxation is incomplete (i.e., subluxation), radiological assessment is more difficult. Radiographs should be obtained in the weight-bearing position and compared carefully with the normal anatomy. When luxation or subluxation is suspected clinically, so-called ‘stress radiographs’ may be helpful to determine the integrity of the periarticular soft tissues such as the collateral ligaments. Stress radiographs are obtained with the limb not weight bearing, with force applied to the joint in either a mediolateral or dorsopalmar direction to determine whether the bones may be moved abnormally in relation to each other (Figures 1.25a and 1.25b). Ultrasonography may yield additional information.

INTRA-ARTICULAR FRACTURES

Intra-articular fractures exist when there is a break in the articular surface. Unless there is some degree of displacement, damage to the articular cartilage may not be seen, but should be assumed to exist. A small degree of displacement is indicated by the presence of a slight ‘step’ in the two sides of the articular portion of the fracture line. Fissure fractures are not displaced and many views may be required in order to identify the fracture, as the x-ray beam must be exactly aligned in the plane of the fissure. Such a fracture may only involve one cortex of the bone.

Fractures of the articular margin are termed chip fractures. Radiographs should be carefully inspected for evidence of additional chips, pre-existing degenerative joint disease, or other concurrent pathology, which may adversely affect the prognosis. Differentiation between chip fractures, ectopic mineralisation and separate centres of ossification may not be possible. The position of the mineralised body relative to the articular margin, the size and shape of the body, and the contour of the articular margin should all be assessed carefully. A recent chip fracture may have a sharp edge, and a fracture ‘bed’ may be discernible. Separate centres of ossification, or old chip fractures, may be very well rounded uniformly opaque bodies, and a fracture bed is usually not detectable. Ectopic mineralisation may be present within the joint capsule following embedding of a displaced mineralised fragment.

A slab fracture is a fracture extending from one joint surface to another, e.g. from the proximal to distal articular surface of the third carpal or tarsal bones. These fractures may be extremely difficult to detect radiographically in the acute stage if not displaced. Oblique views, including skyline views, are invaluable in the carpus. In the tarsus it may be necessary to re-radiograph the joint after 7–10 days when some demineralisation has occurred along the fracture line.
Infectious arthritis is most commonly seen in young foals, and frequently involves several joints. It may occur in an adult, usually associated with trauma, but may be iatrogenic. Radiographic features of joint infection include:

- Periarticular soft-tissue swelling
- Joint capsule distension, with or without apparent widening of the joint space
- Irregularity of outline of the subchondral bone
- Lucent zones in the subchondral bone, with or without areas of increased opacity
- Periarticular osteophyte formation, due to secondary degenerative joint disease
- Partial collapse of the subchondral bone.

The presence of bony abnormalities indicates that the disease is advanced and warrants a guarded prognosis. The absence of detectable radiological abnormalities does not preclude a diagnosis of infection. The speed of development and degree of cartilage and bone destruction depend on the causative organism.

In a neonate, care should be taken to differentiate the radiographic appearance of incompletely ossified bones, which may have an irregular outline and granular opacity, similar to that seen in infection. Reference should be made to the text in the subsequent chapters, which describes the appearance of incomplete ossification where it is a normal feature at birth. In a foal, joint infection may develop secondarily to infection of an adjacent physis, or may spread from a joint to an adjacent epiphysis.

Firth (1983) classified infectious polyarthritis of foals into several syndromes as follows:

1. Physeal type P osteomyelitis. There are areas of irregularity and focal widening in the physis. At this point the term physitis may appear more appropriate than physeal osteomyelitis; however, once the changes have advanced sufficiently far to be seen radiographically, there is usually also involvement of the metaphyseal or epiphyseal bone adjacent to the site of origin. Infection may continue to extend into the epiphysis or metaphysis, where the infection is characterised by relatively opaque areas of bone surrounded by lucent areas. These are frequently triangular in shape. As the condition progresses, soft-tissue swelling associated with the joints may be seen, and this may develop into infectious arthritis secondary to underlying osteomyelitis.

2. Type E osteomyelitis begins in the epiphysis and progression is similar. The classification is only used to denote where the nidus of infection was established.

3. Type S osteomyelitis actually begins in the synovium, and extends from there, rapidly becoming septic arthritis, or extends into the physis and possibly also the metaphysis and epiphysis.

4. Type T osteomyelitis is limited to the tarsus and must be differentiated from aseptic necrosis of the central and third tarsal bones. Type T cases usually present because of generalised tarsal enlargement or tarsocrural joint capsule distension. Although the central and third tarsal bones are occasionally involved, the majority of pathology is noted in the distal tibial physis and/or tarsocrural joint. The main radiographic findings include soft-tissue...
swelling, distension of the tarsocrural joint and irregularity of the distal tibial physis (type P osteomyelitis). When the central and third tarsal bones are involved, they are normal in shape but have a mottled lucent appearance.

5 Type C osteomyelitis. Recently osteomyelitis of the carpal bones has been described, and appears similar in many respects to tarsal osteomyelitis. It may therefore be appropriate to include a fifth category in Firth’s classification – osteomyelitis identical to type T, but localized to a single carpal bone (Figure 7.21a,b).

**Synovial osteochondromatosis**

Synovial osteochondromatosis represents a very unusual synovial response in the horse and can be primary or secondary. The condition describes metaplastic and focal formation of cartilage within the intimal layer of the synovial membrane. The condition is also uncommon in other domestic animals, although it occurs more frequently in humans. Cartilage may undergo mineralisation and become evident radiographically. Treatment usually involves arthroscopic removal of osteochondral bodies and resection of abnormal synovium. Recurrence is quite common and malignant transformation rarely occurs, although, to date, this has not been reported in the horse.

**Subchondral bone cysts and osseous cyst-like lesions**

The terms subchondral bone cyst (SBC) and osseous cyst-like lesion (OCLL) are sometimes used loosely to describe the same lesions. They are usually solitary, circular lucent areas in a bone, which may be surrounded by a narrow rim of increased opacity. They are usually unicameral (single chambered) but may be multcameral. They are often close to the articular surface of the bone and sometimes a ‘neck’ connecting the cyst-like lesion with the joint surface can be identified.

Differentiation between an SBC and an OCLL cannot be made based on their radiographic appearance, but is based on the gross structure.

An SBC is a structure with a fibrous lining and filled with fluid or semi-solid tissue. Cysts in some locations in some joints fulfil these criteria (e.g. medial femoral condyle), but there is limited information available about the infrastructure of cysts in many locations so these are described as OCLLs. Some OCLLs ultimately fill in radiologically, but others persist virtually unchanged. Osseous cyst-like lesions and SBCs occurring near the articular surface in young horses may appear to migrate progressively away from the joint surface, as normal endochondral ossification occurs.

An SBC and some OCLLs may first be identified as a small lucent depression in the articular surface (see Chapter 10, ‘Osseous cyst-like lesions’ and Figure 10.21). This progressively enlarges and a rim of increased opacity may develop around the cyst-like lesion. They are often close to the articular surface of the bone and sometimes there is a ‘neck’ visible connecting the cyst with the joint surface. The radiographs should be carefully examined for evidence of concurrent secondary degenerative joint disease.

The exact cause of SBCs and OCLLs is uncertain. It has been suggested that they are part of the osteochondrosis syndrome, but the evidence for this is limited. There is evidence that some SBCs and OCLLs are traumatic in origin. An OCLL may develop in association with degenerative joint disease and there are probably other aetiologies which have not been identified.
Osseous cyst-like lesions which occur deep within bone, such as in the carpal bones, are rarely associated with lameness, whereas SBCs and OCLLs close to an articular surface, such as in the medial femoral condyle, are frequently associated with lameness. Small OCLLs in the phalanges have been identified close to articular margins as incidental findings of no clinical significance; some of these have been seen to disappear radiographically with conservative management.

Osteochondrosis

Osteochondrosis is considered to be a disturbance of endochondral ossification, but there is increasing evidence to show that there may also be primary subchondral bone lesions. The disease may be generalised, although only evident radiographically in certain joints. The femoropatellar, tarsocrural, metacarpophalangeal or metatarsophalangeal (fetlock) and scapulohumeral joints are the most commonly affected in the horse (see Chapters 10, 9, 5 and 8, respectively). The radiological appearance of osteochondritic lesions is variable among individuals, and the joints involved, but the changes normally include:

- Discrete osteochondral fragments
- Alterations in the contour of the articular surface, e.g. flattening or a depression of the subchondral bone plate
- Irregularly shaped lucent zones in the subchondral bone
- Increased opacity surrounding the lucent zones
- Secondary modelling of joint margins.

Lesions are not always of clinical significance but must be interpreted in the light of the clinical signs. Some lesions remodel gradually and become increasingly opaque and may eventually “heal” radiographically. Clinical signs are generally recognised in horses less than 3 years of age, but occasionally horses remain asymptomatic until later in life, especially if the horse does not work until a later age.

Degenerative joint disease

Degenerative joint disease (DJD), osteoarthrosis, osteoarthritis and secondary joint disease are often used synonymously in veterinary medicine, yet distinctions can be made in some cases.

Arthritis simply means inflammation of a joint, and if recognized radiographically is seen as joint capsule distension without evidence of new bone involvement. There is inflammation of the synovial lining and changes in the quantity and quality of synovial fluid. Osteoarthritis or osteoarthrosis indicate that bone has become involved and that an inflammatory soft-tissue component may (itis) or may not (osis) be present. The term secondary joint disease is used when the primary cause is known, such as in osteochondrosis or intra-articular fracture. Degenerative joint disease is used to refer to any number of causes that affect the joint and its supporting structures. In the horse, the degenerative process, which results in DJD, may be associated with poor conformation and/or hard use. Advanced DJD, however, is sometimes seen in immature horses, less than 3 years of age, with no identifiable predisposing cause. Any condition that damages cartilage directly, causes joint instability, or subjects the joint to abnormal directional forces, can
cause DJD. Immune-mediated joint disease should be considered whenever there is polyarthritis and sepsis can be ruled out.

Radiographic abnormalities (so-called cardinal signs) associated with DJD include:

- Periarticular osteophyte formation
- Increased opacity of subchondral bone, and loss of trabecular pattern
- Ill-defined small lucent zones in the subchondral bone
- Small well-defined osseous cyst-like lesions
- Narrowing of the joint space
- Joint capsule distension
- Periarticular soft-tissue swelling.

One or more of the above may be seen in association with DJD in any joint. If possible, periarticular osteophyte formation should be differentiated from enthesophyte formation. Small periarticular osteophytes are not necessarily synonymous with clinically significant DJD. It must also be borne in mind that the absence of detectable radiological abnormalities does not preclude the presence of cartilage degeneration. As DJD progresses, radiological abnormalities become more obvious. Ultrasonography may give useful information about the integrity of the articular cartilage.

**Dystrophic and metastatic mineralisation (calcification)**

Calcium is seldom deposited alone. Even in bone the opacity seen on radiographs is due to a mixture of calcium, phosphorus, zinc, manganese and magnesium, and therefore dystrophic and metastatic calcification is more correctly termed mineralisation. Mineralisation in soft tissue can occur in association with inflammation, neoplasia, trauma or metabolic disease. The most reliable indication of the cause of the mineralisation is the location in which it occurs, combined with knowledge regarding the organs or structures located in the area. Knowledge of what diseases result in mineralisation of a particular organ provides valuable information, and occasionally a definitive diagnosis. The size, shape and pattern of mineralisation may vary, and therefore are poor indications of a specific aetiology.

Soft-tissue mineralisation has been classified as being metastatic or dystrophic. Metastatic mineralisation is the deposition of minerals in tissues that have not previously been damaged. It is associated with hypercalcaemia, hypercalciura and hyperphosphataemia.

Dystrophic mineralisation is the process whereby mineral is deposited in injured, degenerating or necrotic tissue, and is commonly seen in the horse. It can occur secondary to any injury to soft tissue, e.g. in tumours that have become necrotic, at the site of fat necrosis, subsequent to infarction, and in association with inflammation or haemorrhage. Either type of mineralisation may eventually result in the formation of mature bone.

**Additional figures**

The book companion website at www.clinical-radiology-horse.com includes additional figures that are not included in the printed book or e-book formats. Please see ‘About the Companion Website’ at the start of the book for details on how to access the website. These figures are prefixed with the letter ‘w’ in the printed book, e.g. Figures 1w.4c–f.


Chapter 2
Computed and digital radiography

Digital radiography is a generic term that has been widely used to describe both computerised (computed) radiography and direct capture digital radiography. Both techniques result in a radiographic image captured electronically and displayed as a digital image on a computer monitor. The image can be archived digitally and/or transferred into a ‘hard copy’ using a laser printer. The generation of the x-ray beam remains unchanged and, just as with conventional film–screen radiography, the quality of the digital image is greatly affected by the quality of the x-ray generator, the radiographer’s technique and the ability of the radiographer to choose correct exposure factors.

New terms have come into common usage. DICOM is an acronym for Digital Imaging and Communication in Medicine and is a standardisation of image format to facilitate exchange of images. A DICOM file contains a header, which gives the patient information and image data relevant to the image. The term PACS, Picture Archiving and Communication System, applies to the combined hardware and software used for digital imaging, allowing communication between computers. As with any computer-based system, training in the use of both hardware and software and in information technology, and maintenance support for the system are invaluable.

Digital processing of radiographic images is a very rapidly developing field. The earliest systems were the computerised radiography systems, and while still widely used at the time of writing, the current research and development trends are primarily with direct digital systems. The current trends in equine radiography are towards wireless direct digital systems for use both in the field and in hospitals as the cost of direct systems becomes less prohibitive. However, computerised radiography in a hospital situation provides more flexibility because two horses can be examined simultaneously. The cost of several large digital radiography imaging plates remains high.

Computerised radiography

Computerised or computed radiography (CR) has similarities to conventional film–screen radiography, despite the absence of film and chemical processing. The phosphor plate, otherwise known as an imaging plate, is stored in a cassette, allowing existing x-ray equipment to be used, but replacing a traditional film cassette with a computed radiography imaging plate.
Computed radiography uses photostimulable phosphors (storage phosphors) to capture the image. The storage phosphors are coated on to either a flexible or rigid plate (dependent on the system), much like screens used in conventional radiography. The storage phosphors come from the barium fluorohalide family, with trace amounts of impurities added to their crystalline structure to alter their physical properties. These are deposited on to the backing plate in powder form, the size of the phosphor grain used influencing the resolution of the system. Low-resolution imaging plates use a larger phosphor grain than high-resolution plates. Most systems are designed to be around 10–20 phosphor grains thick.

Computed radiography storage phosphors differ from traditional screen phosphors because instead of emitting light in response to the incident radiation, they store the energy as a latent image. This is subsequently stimulated using a laser beam, and released in an image plate reader. The amount of energy released is directly proportional to the intensity of radiation reaching the imaging plate during exposure.

**Imaging plate reading**

In most commercially available systems a flying spot readout system is used. In this system a laser spot scans the exposed plate using a mirror in a point to point raster pattern. This causes the phosphor to release the stored energy as a violet blue glow. The intensity of the phosphor glow is directly proportional to the amount of energy stored from the exposure made. The glow is captured by the system and enhanced using photomultiplier tubes. The resultant optical signal is converted into a digital signal using an analogue-to-digital converter. The digital signal is processed within the control computer using algorithms predetermined for different body parts. The total processing time is currently between 40 and 90 seconds, depending on the system, and only one imaging plate can be read at a time. The systems are developing rapidly, and readers are advised to seek up-to-date information if considering purchase of any digital system.

The resultant image should be transmitted to a high-resolution monitor for image reading. With the larger stationary readers the image is displayed on an adjacent workstation monitor on which the image can be checked for appropriate positioning and exposure. However, the image is usually displayed at a much lower resolution than the information captured and this image should not be used for diagnostic purposes.

The laser scan does not release all the energy stored in the phosphor. After scanning, the plate requires an erase cycle, in which the phosphor plate is exposed to a bright fluorescent light. This removes any remaining residual energy, enabling the plate to be reused. This process takes up to 30 seconds.

The latent image can be stored for up to 24 hours, but generally it is best to ‘read the plate’ as soon as possible after exposure. Just as with conventional film-screen radiography, it is possible for dust and other foreign bodies to get into the cassette holding the imaging plate, therefore regular cleaning using the manufacturer’s recommended procedure (e.g. pure alcohol and lint-free wipes) is essential. The imaging plate must be allowed to dry before it can be reused, so this is a procedure to be carried out at the end of a day. There should be a regular system of cleaning and a log maintained.
The plates can be subject to physical damage, either during exposure or in the plate reader, both of which can result in artefacts. Correct handling of the plates is therefore important.

DIRECT DIGITAL RADIOGRAPHY

Direct digital, direct digital capture, direct radiography (DR) and digital radiography are synonymous terms used to describe a system which converts the x-ray photons to a digital signal without the use of a phosphor plate. This saves considerable time and energy. As with computed radiography, direct digital radiography is used in conjunction with conventional x-ray machines. There are two types of sensors (panels) currently in use. In both types the image is captured by an electronic array, and transmitted directly to a computer to generate the required image. The image is initiated by a thin layer of scintillation material made of caesium iodide, which emits light when stimulated by x-rays. Under this layer of scintillant is the recording layer. In a charge-coupled device (CCD plate) under the scintillation layer are myriad chips, electronically coupled together. The more reliable but more expensive panels use a layer of amorphous silicon as a detector (like one huge computer chip), converting the light into digital data. In direct digital systems the digital data is transmitted either directly via a cable attaching the panel to the processing computer, or via a radio link to the computer. In either case the image appears on the monitor in a few seconds.

The purchase price of a direct digital radiography system is currently becoming comparable to computed radiography. Large (26×32 cm) panels are becoming affordable, allowing the use of direct digital radiography for areas other than the distal aspect of the limbs. The cable connection to the computer which processes the image may be of some concern when dealing with a horse that is difficult to restrain, with an inherent risk of damage to the equipment. Since images can be read within a few seconds however, there are potential time savings compared with either conventional radiography or computed radiography. Wireless systems are now replacing cables, and while they have been slower to transfer data than the cable systems, as development proceeds this is becoming less of a problem, and it is likely that cable systems will become uncommon as time progresses. At the time of writing, the most sensitive panels in production are for wireless DR systems.

Development of these systems progresses rapidly, and as the processing systems are becoming lighter and more sensitive, the development of battery-powered x-ray generators is also progressing. Fully portable battery-powered x-ray systems are now available, with the generator and processing systems linked, and exposure values fully automated, controlled by feedback from the sensor to the generator. Such systems currently only have enough power for distal limb radiography, but in the foreseeable future this may also change.

IMAGE RESOLUTION

Images are comprised of pixels and the pixel size determines spatial resolution, the ability to define two objects close together. To increase resolution the number of pixels is increased without changing the field of view (the physical area being examined), thus decreasing the matrix size. A 2048×2048
(2-K) matrix or higher is recommended for digital radiography. Dynamic range refers to the number of shades of grey that can be represented. Each pixel has a bit depth which determines the number of shades of grey that can be represented. Eight bits represents a greyscale range of 256 ($2^8$), ranging from 0 (white) to 255 (black). The human eye can only resolve a limited number of shades of grey, therefore excessive bit depth results in large file sizes without providing additional useful information. The dynamic range of most digital x-ray systems is determined by the computer and software. Most use an 8-, 10- or 12-bit dynamic range (i.e. $2^8$, $2^{10}$ or $2^{12}$). The American College of Radiologists recommends a minimum of 10-bit depth.

EXPOSURE FACTORS

When choosing exposure factors for digital radiography it is important to recognise the change in technology from conventional film–screen radiography and how to optimise exposure factors, which are different for digital systems. In film–screen radiography mAs controls the opacity of the image. This is because the same medium is used for detection of the photons and for the display of the resulting image, making them intimately linked. In digital radiography the image display and image detection are separated. The mAs still determines the number of photons absorbed into the imaging plate, which affects the density and the noise in the stored image, but this data is also subjected to image processing in the form of algorithms. These algorithms control the display of the signal and hence the image opacity seen on screen.

kVp controls contrast in both film–screen and computed radiography, higher kV penetrating denser tissues better. With conventional film–screen radiography the response is non-linear, which means that matching of subject contrast to kVp and film–screen combination is important. With digital radiography the response is linear and it can therefore compensate for loss of subject contrast through image processing and algorithms. Thus digital radiography offers higher contrast resolution and exposure latitude compared with conventional film–screen radiography.

When choosing an exposure it is still important to adjust kVp and mAs to body part and size of the individual, but it is equally important to choose the correct algorithm which controls how the image is displayed. It is not necessarily straightforward to determine whether the imaging plate has been under- or overexposed, because the displayed image is further processed.

Overexposure

With conventional film–screen radiography an overexposed image appears relatively black throughout and an underexposed image appears relatively white (assuming there are no development problems). With digital radiography the digital image is selected from a portion of the black–white spectrum. Overexposure may take the image out of the part of the spectrum being read by the computer, thus it does not result in overall blackening of the image, but the image appears light, white, or pale (Figure 2.1a). A region of the image may be overexposed compared with the rest of the image, and this can mimic a lesion or create a region that cannot be accurately interpreted.
Underexposure

With conventional film-screen radiography an underexposed image appears relatively white (assuming there are no development problems). With digital images an underexposed image may appear dark. It will usually however have a grainy, mottled appearance. This is caused by image noise, created because there is inadequate data for the computer to assign a grey shade to the underexposed region of the image. Graininess may obscure detail, for example trabecular architecture.

Each manufacturer’s system produces a figure which gives an estimation of whether or not the exposure was appropriate. Different manufacturers use different terminology for this figure and have a different range they consider appropriate. Terminology includes exposure index, S value, DDI and REX. To determine whether an image needs to be repeated the exposure index (or equivalent) should be consulted. If this figure is within reasonable limits (set by the manufacturer’s guidelines), an image acquired using computed radiography can be manipulated on the display rather than repeated.

Algorithms

Algorithms process the image stored on the system, and determine how it is displayed. They can give different weight to different areas of the black-white spectrum, and therefore play an integral part in how the image is displayed. In some instances they can be modified by the user, however it is vital that appropriate training by the manufacturer has been given. If images of certain specific body areas are not being adequately displayed, then assistance with modifying algorithms should be sought from the service provider.

Imaging an area within which there are tissues of widely differing densities potentially poses some difficulties, and it may result in the more dense area appearing completely white and without detail and less dense areas being black and ‘burnt out’. Most systems can display a histogram of pixel density across different areas, and/or have other features to indicate areas that are outside the readable densities. It is important to recognise these areas, and if they contain potentially important information, then additional images, with exposure factors adjusted accordingly, are required in order to obtain the missing information.

Grids can be used with both computed and digital radiography, but may cause problems, and the manufacturer of the system should be consulted for advice. With a CR system grid lines that have a similar frequency (lines/cm) as the laser reader cause a wavy (moire) pattern of lines (Figure 2.2) that may destroy image quality. Other combinations can also be a problem. Generally grids should have at least 60 lines/cm and grid lines should preferably run perpendicular to the plate reader’s laser scan lines. However some systems have grid line removal software that may eliminate this problem. In the authors’ experience, while grids remain important for radiography of thick areas such as the thoracolumbar region, they can often be dispensed with for imaging the distal aspects of the limbs. It may be necessary to borrow several grids from the manufacturer to determine which is most appropriate. In some instances the use of an air gap between the patient and the imaging plate may be more appropriate than a grid, but this does lead to magnification of the image.
Appropriate collimation of the x-ray beam and standard focus–image plate distances (source–image distances) are particularly important with digital imaging in order to achieve optimal image quality. Lack of collimation can affect the algorithm and the appearance of an image because the system processes the whole of the image as one exposure. This can be improved in some systems by selecting the area to be processed. The better the initial image however, the better will be the end result, despite all processing applied to the image. Collimation is particularly important in areas with large changes in density of tissues within the exposed area (Figures 2w.1a, b and c). The system looks for unexposed black and grey areas and tries to subtract white areas so that only useful information is processed. The system effectively looks for collimation lines. Good collimation also eliminates scattered radiation at acquisition; collimation of an image in the software will not remove scatter (Figures 2w.3a and 2w.3b).

MONITORS

When reviewing digital images it is important to choose the highest-resolution monitor that is affordable. Cathode ray tubes (CRTs) are seldom used nowadays, images usually being produced on active-matrix liquid crystal displays (AMLCDs).

[46]
The resolution of monitors is measured by the number of pixels displayed on the screen at any one time. This is displayed as two numbers multiplied together, which is often abbreviated, e.g. a $1024 \times 768$ pixel monitor and a $1600 \times 1200$ pixel monitor are referred to as 1 Meg (megapixel) and 2 Meg monitors respectively. With 3 Meg and 5 Meg monitors widely available, the limiting factor is cost. Monitor specification also includes spatial resolution and contrast resolution. Spatial resolution is described as either pixels/mm or line pairs/mm. Three millimetres per pixel is equivalent to 6 mm/line pair. Contrast or depth resolution is described as grey values or bits. An 8 bit image has 256 grey levels; a 12 bit image has 4096 grey levels. However, the human eye can only resolve approximately 100 scales of grey. The American College of Radiologists has recommended that computed radiography image capture should be digitised to at least 2.5 line pairs/mm and that the image should be digitised to 10 bits per pixel or more.

The monitor ideally should be a true DICOM monitor and not just a DICOM-compatible monitor. The DICOM-compatible monitor only shows a representation of a DICOM image; the grey scale is reduced, and greatly affects the image quality. The high-resolution DICOM-compatible monitors on the market should be able to display digital images in varying degrees of luminance with various background colour settings that are similar to film choices. This should aid user preference being accommodated when viewing radiographs, and allow adjustment for the lack of grey scale.

**COMPUTED RADIOGRAPHY ARTEFACTS**

**Imaging plate artefacts**

Flexible imaging plates are found in many tabletop/compact computed radiography systems and are very susceptible to cracking. This generally starts around the edges, and will then begin to spread into the more central areas of the plate, overlying the image being examined. These artefacts may appear on radiographs as linear radiopacities or radiolucencies. If this occurs it is imperative that the plate is replaced.

Backscatter from dense objects behind the imaging plate can cause the plate to be exposed from behind, creating a ‘ghost-like’ image over the radiograph. This is more likely with large exposures. It can be prevented by placing a piece of rubberised lead or equivalent behind the cassette to absorb the scattered radiation.

Hair stuck on the imaging plate results in a linear curved white artefact, because anything blocking the imaging plate’s emission of light will be blocked when scanned by the laser in the reader. Other debris causes a white artefact of variable shape. A linear black line on one side of the image can be the result of backscatter transmitted through the cassette hinge.

**Plate reader artefacts**

Imaging plates are automatically erased after they are read, to prepare them for the next exposure. If imaging plates have not been used for a period of time, they should be manually erased before use. Imaging plates are sensitive not only to x-rays but also to other electromagnetic radiation.
Computed and digital radiography

(uvaviolet and gamma rays) and particulate radiation (alpha and beta radiation). These are present as natural background radiation. Thus imaging plates are susceptible to background noise creating black dots (Figure 2.4a), unless manually erased shortly before use (Figure 2.4b). Most computed radiography readers have a dedicated erase cycle and manufacturers will provide guidelines on the maximum recommended period of time between erasure and usage.

Some manufacturers provide more than one erasure setting; if an incorrect exposure is made it is vital to choose the correct setting to ensure the plate is fully erased. If this does not happen it could result in a ‘ghost’ image from the previous exposure appearing on the next radiograph.

Dirt and dust in the plate reader can attach to the reader optics, which can cause horizontal or vertical white lines on images depending on the orientation of the plate. If lines are seen it is important to have the plate reader serviced to clean the particles from the optics or mirror. To maintain cleanliness

Figure 2.4(a) A poor-quality caudocranial radiographic image of an immature stifle obtained using a computed radiography system. Superimposed over the denser tissues of the femur and surrounding musculature is a dark speckled pattern, an artefact created by the digital system. This can occur when there are tissues of greatly varying opacity within the area being examined.

Figure 2.4(b) Background noise, the result of processing a computed radiography imaging plate that had not been cleared for several days.
the reader should be in a dust-free environment. Imaging plates should be cleaned on a regular basis (as directed by the manufacturer), and the plate housing should be cleaned before submitting plates to be read. Multiple lines may appear across an image, which represent an artefact during image acquisition or processing (Figure 2.5).

**Operator-induced artefacts**

Operator errors may be more frequent in instances where a new computed radiography machine has been installed as a replacement for conventional screen–film combinations. It is important to store the imaging plates correctly. They must be protected from direct heat and extremes of humidity to prevent environmental damage to the imaging plate, and should also be stored where they will not be subjected to inadvertent exposure either from a direct exposure or from scatter. They are much more sensitive to scattered radiation than a conventional film–screen cassette.

As with film–screen systems, it is also important to identify the correct side of the cassette for exposure. This should be easily recognisable, and is often marked with a sticker stating ‘tube side’. If an exposure is made on the wrong side, there will be a distinctive pattern across the image, resulting in the need for a repeat.
IMAGE READING

The angle of the monitor can influence the information that can be obtained from the image. The image should be viewed from perpendicular to the monitor because contrast ratios can change rapidly (10:1) for a change in viewing angle from 90° to 85°. Ambient light is also critical to minimise reflections on the monitor. If using a laptop computer it should have an antireflective or antiglare screen. The monitor should be viewed in dim light; ideally the reading room should be illuminated at 2–25 lux (sunlight is 105 lux). A room fitted with blinds to obscure direct sunlight is ideal. When acquiring x-rays in the field, they should be reviewed once back at the practice under optimum viewing conditions.

Image manipulation

The image can be manipulated in a variety of ways, including alteration of brightness and contrast, magnification, and by edge enhancement. Alteration of brightness and contrast should enable thorough examination of the internal architecture of bone, the bone margins and the surrounding soft tissues on a single image, if these were not evident on the original image (Figures 2.6a and 2.6b). Thus potentially more information can be gained with appropriate

Figure 2.6(a) Lateromedial image of an immature stifle obtained using a computed radiography system. Cranial is to the left. The image has been windowed for optimal evaluation of the internal osseous architecture.

Figure 2.6(b) Lateromedial image of an immature stifle obtained using a computed radiography system. This is the same as Figure 2.6(a), obtained at the same exposure (i.e. identical exposure factors and algorithm), but the image has been windowed to permit better evaluation of both the soft tissues and some of the bone margins cranially.
manipulation. Maximal information will always be obtained from a well-positioned, appropriately exposed image, and digital imaging and image manipulation are not a substitute for poor technique. Digital imaging provides the opportunity to enhance good radiographic technique.

It is necessary to learn how to examine a digital image. With both a conventional film–screen image and a digitally acquired image it is important to view the image both from a distance and close up. With a conventional film–screen image it is important to use high-intensity illumination to examine bone margins more closely. With a digital image the reader should examine the entire image making use of the windowing facility to alter brightness and contrast as necessary (Figures 2.7a and 2.7b), to evaluate all the structures in the image. Use of the inverted window can help to identify more subtle changes, e.g. periosteal new bone (Figures 2w.8a and 2w.8b). However, with optimal exposure factors and algorithms, little image manipulation should be necessary. The use of edge enhancement may or may not help image interpretation, by increasing the contrast between areas of different densities. Incorrect use of edge enhancement may produce confusing artefacts. For example, it may create the impression of increased bronchial wall opacity in a thoracic image. Enlarging the image is often useful, but excessive enlargement results in the image becoming more pixelated (grainy) and potentially more difficult to interpret. It is also important to recognise that when examining large bones, such as the distal aspect of the femur, windowing the image by alteration of the brightness and contrast may result in the apparent development of radiolucent areas (Figure 2.9) which should not be misinterpreted as pathological lesions. Because the brightness and contrast of images can be manipulated easily, detection of conditions such as osteoporosis or increased lung density becomes more difficult.
The size of the displayed image is scaled according to the screen size, so real size may be more difficult to determine. Many images have a scale at the side of the image, and if this is present then very accurate measurements can be made much more easily than on conventional radiographs. Some software allows ‘true’ size measurement calibration. Angle measurements can also be obtained. A ratio measurement facility is useful for sagittal ratio measurements of the cervical spine.

It should be possible to show more than one image on the monitor simultaneously in order to compare different views of the same area, or to compare images obtained on two different occasions. This facility is a feature of the software provided with the system. The ease with which previous images can be recalled for viewing depends on the system and method of archiving.

**IMAGE ARCHIVING AND TRANSMISSION**

Digital radiography removes the necessity for hard copy. It can also make image retrieval much easier. All images can be stored electronically and the method used depends on the number of images acquired daily. The retrieval systems vary considerably and it is important to establish how images can be searched, e.g. patient name, owner, case number, area examined. Whatever system is used for image storage, it is vital that it is backed up as for any computer system, to ensure data is not irretrievably lost. Some systems have an automatic back-up system (e.g. CD burn and autorun), but others require a regular back-up protocol to be instituted. (Images can be stored on magnetic disk (hard disk), DVDs (digital versatile disks), optical disks or magneto optical discs.)
A DICOM server can be used for data storage in a multisite practice that can be accessed via a telemmedicine network, allowing any authorised user connected to the system to view and handle files from many sites. Additional software may be required to function fully with some management systems.

Teleradiology is the electronic transmission of radiographic images from one location to another for the purposes of interpretation and/or consultation. Although in theory digital images can be readily e-mailed, they do create large data files, which may not be suitable for transmission, unless specialised software is used. The reader should refer to their system advisers for up-to-date details of this rapidly changing field. Images can readily be saved to CDs, allowing transfer of information between users. It is necessary however to ensure that, if DICOM files are used, the recipient of the disk has the necessary software to read the information. Many manufacturers now provide a software viewing package that is loaded on to the disk with the digital images. There are many companies that facilitate transfer of large data files.

Conversion to a compressed format allows more efficient storage and transmission. The original DICOM image can be compressed with patient data attached, or files may be compressed by conversion to other formats. This may open the opportunity for fraudulent manipulation of images, and so should only be used with due consideration. Developments in software and hardware are progressing so rapidly that it is not sensible for a book such as this to offer further detailed advice on storage and manipulation of files, as it will inevitably be out of date before the book is published!

A potential problem with digital radiography is the different file formats in which images may be saved, which can lead to difficulties when being opened by a remote user. Although some systems load viewer software with the images on to a CD or DVD, this is not universal. The files may not open with standard Windows applications and the header information (patient details) may be inaccessible. Some systems open automatically in their own format, but for others special software and a DICOM viewer are required. Many modern veterinary computer systems running with Windows already have a DICOM viewer installed, but this is not universal.

Software and software tools for viewing DICOM images are not standardised. Some are more intuitive to understand than others. As with most Windows software, placing the mouse arrow over the tool symbol will usually produce a short text describing the function of the tool, but if images have been sent from another country, this is likely to be in the language of the country of origin of the images. It may be necessary to resort to trial and error, in the knowledge that with true DICOM files if the result is not what was wanted, the operation can be cancelled and the image returned to the original stored image.

**ADVANTAGES OF DIGITAL RADIOGRAPHY COMPARED WITH CONVENTIONAL FILM–SCREEN RADIOGRAPHY**

The capital costs of digital equipment can be weighed against the absence of costs of conventional film and the chemicals required for processing. Digital systems eliminate the potential health and safety and environmental issues of darkroom processing, and eliminate the need for a darkroom. They also eliminate the environmental hazard of disposal of processing chemicals. Digital imaging should also reduce the number of images
acquired, because fewer repeat x-rays are needed due to inappropriate exposures, and fewer repeat images are needed with different exposures to detect specific lesions. There is reduced storage area needed for both processing chemicals and archiving of x-rays. The risk of processing artefacts is reduced. The time taken to obtain images is also reduced, especially with direct digital radiography. For a practitioner in the field, acquisition of images with digital radiography is no longer limited by the number of available cassettes. Images can be viewed on a laptop computer in the field, and although this may not have the same resolution as a better monitor, the images can be assessed for suitability of positioning and a preliminary diagnosis made. The development of battery-powered x-ray generators for use with more sensitive DR imaging plates, and smaller computers to process the images is making portable x-ray systems truly available in almost any circumstances. Whether radiography should be attempted in all these circumstances is open to debate. It is crucial that appropriate radiation safety measures are employed.

Images are readily archived, and retrieval should be easier and more reliable than with conventional radiographs. Images are less likely to be lost (assuming that files are backed up), or misfiled. Image quality should also be stable over time. Images can easily be transmitted electronically making it much easier to obtain a second opinion on interpretation. Images acquired on behalf of a prospective purchaser can easily and rapidly be sent to their own veterinary surgeon or insurance underwriter’s veterinary surgeon for independent review.

Although theoretically film–screen radiographs contain more detailed information than computed or digital radiographs, given equivalent standards of radiography, in practice we have found that image quality and diagnostic capabilities have actually increased using digital systems. For example, the recognition of osseous fragments distal to the medial and lateral angles of the distal border of the navicular bone has increased. The potential for increased detail means relearning what is normal, and not over-interpreting normal findings as pathological lesions. Over-interpretation is a common problem when first using a digital system (Figure 2.9).

Additional figures

The book companion website at www.clinical-radiology-horse.com includes additional figures that are not included in the printed book or e-book formats. Please see ‘About the Companion Website’ at the start of the book for details on how to access the website. These figures are prefixed with the letter ‘w’ in the printed book, e.g. Figures 1w.4c–f.

FURTHER READING


Chapter 3
The foot

The foot is a complex area, involving several bones and important soft tissue structures as well as the hoof wall. This chapter has therefore been subdivided into anatomical areas in order to make description easier. Although several of these areas may be obtained on a single radiograph, radiographs centred on the area of interest are required for accurate appraisal.

Except where stated otherwise, the text refers to both front and hind feet.

Distal phalanx (pedal bone)

RADIOGRAPHIC TECHNIQUE

Equipment

Radiographs of the distal phalanx (third phalanx, pedal bone) can be obtained with low-output (minimum 15 mA) portable x-ray machines. Digital imaging or slow, high-detail screens with compatible film are recommended to obtain maximum definition.

Prior to obtaining radiographs, the shoe should be removed and the sole and hoof wall cleaned of mud and dirt. Loose flakes of horn from the sole, bulbs of the heel and frog should be trimmed. Particular care should be taken if the frog clefts are deep. A sharp pointed instrument, such as a searching knife, a hoof pick or rat tail file, is helpful for removal of packed debris. The clefts should finally be cleaned using a stiff brush. Radiographs of the distal phalanx do not normally require the foot to be packed, although packing around the point of the frog will eliminate air shadows from the foot and may avoid confusion in some cases, especially if a fracture is suspected. Care must be taken to ensure that the sole is packed evenly, because the low exposures required to assess the solear margin of the distal phalanx can also result in images of uneven packing. Loose packing may mimic, or mask, fractures; excessive packing may create radiopaque artefacts (Figure 3.1). These packing artefacts are particularly evident on digital radiographs. Previous paring of the foot in search of a sub-solear abscess may result in confusing radiolucent areas superimposed over osseous structures.

Lateromedial and dorsopalmar or plantarodorsal views of the distal phalanx may be obtained using a grid (see relevant view for details), although this is not essential. Oblique views, particularly palmaroproximal-palmarodistal
oblique and dorsoproximal-palmarodistal oblique views of the palmar processes, and soft exposures (e.g. radiographs to assess separation of the hoof wall from the distal phalanx, lucent lines in the dorsal hoof wall, or subtle modelling of the extensor process), are best obtained without a grid. When using digital systems, grids may cause moiré lines on the image, and so radiographs of areas such as the distal phalanx are better obtained without a grid.

**Positioning**

Any examination of the distal phalanx should always include lateromedial and dorsoproximal-palmarodistal oblique views. Mediolateral views have a similar appearance to lateromedial views and may be used if preferred. For hind feet it may be easier to obtain plantarodorsal rather than dorsoplantar views.

**Lateromedial view**

Lateromedial views of the distal phalanx normally require the foot to be raised on a block of sufficient height to bring the solear surface of the foot level with the centre of the x-ray beam. This also allows the bottom of the cassette to be placed lower than the solear surface of the foot, so that it is included on the image. Ideally both feet should be on a block so that the horse is weight bearing evenly on the foot to be radiographed. The cassette can be supported on the floor, or on a second block, to minimise the risk of movement blur. The x-ray beam should be horizontal, and centered on the distal phalanx, aligned parallel with a line drawn tangential to the bulbs of the heel. Care must be taken when assessing the hoof–pastern axis with this technique, since this will be altered if the horse is not fully weight bearing on a level surface. An 8:1 ratio grid will give the best results for this view when using film, but acceptable results can be obtained without the use of a grid. Digital images are best obtained without a grid.

A survey lateromedial view of the entire foot and pastern may be obtained. In this case the maximum information will be obtained if the x-ray beam is centered on the navicular bone – the beam should be centered approximately
1 cm below the coronary band, and midway between the most dorsal and most palmar aspects of the foot at the level of the coronary band. The x-ray beam should be aligned parallel with a line drawn tangential to the bulbs of the heel. The importance of a true lateromedial view for accurate interpretation cannot be overemphasised. This may be difficult to obtain in horses with marked distortion of the hoof capsule, obvious toe-in or toe-out conformation, or if there is a poor medial–lateral hoof balance. If specific lesions of the distal phalanx are anticipated, the x-ray beam should be centered on the lesion, or on the distal phalanx, at approximately the region of insertion of the deep flexor tendon – a point approximately midway between the coronary band and the ground surface at the junction of the dorsal and middle thirds of the hoof. The beam should be aligned parallel with a line drawn tangential to the bulbs of the heel.

**Dorsoproximal-palmarodistal oblique view**

A dorsoproximal-palmarodistal oblique view gives good visualisation of the body, solear margin and palmar processes (wings) of the distal phalanx, and is suitable for use as a routine view. It may be obtained in one of two ways. The technique giving least distortion is the ‘upright pedal’ view. The toe of the foot is placed on a wooden block with a groove cut along its top surface (referred to as a ‘navicular block’, see Figure 3.63c), and the limb is manipulated until the sole of the foot is vertical. A horizontal x-ray beam is centered on the coronary band and aligned perpendicular to the sole of the foot (Figure 3.2a). The imaging plate is positioned vertically against the sole of the foot. A low-ratio grid (6:1) is ideal for this view when using film, but acceptable results can be obtained without the use of a grid (Figure 3.2b). For digital images, better results may be obtained without a grid.

![Figure 3.2(a)](image1) Positioning to obtain a dorsoproximal-palmarodistal oblique (‘upright pedal’) image of the distal phalanx. The x-ray beam (arrow) is centered on the coronary band.

![Figure 3.2(b)](image2) Dorsoproximal-palmarodistal oblique radiographic image of the distal phalanx of a normal adult horse, obtained using the ‘upright pedal’ technique. The image was acquired with the toe of the foot in a v-shaped block; the horizontal line across the image is created by the block.
For hind feet it is often preferable to obtain a plantarodorsal view rather than a dorsoplantar projection of the foot. This allows good assessment of the structures within the foot and makes little difference to interpretation of radiographs of the distal phalanx. The foot is positioned in a similar manner to that for a dorsoproximal-palmarodistal oblique view. Often the toe may simply be rested on a plane block, and supported by an assistant with the sole vertical. The x-ray beam is centered on the middle of the frog, perpendicular to the sole of the foot. The imaging plate is positioned vertically, dorsal to the foot, and as close to the foot as possible.

A similar view, a dorsoproximal-palmarodistal (high coronary) oblique, may be obtained with the horse standing on a tunnel containing the cassette. The x-ray beam is angled in a dorsoproximal-palmarodistal oblique direction, at approximately 65° to the horizontal, centered on the coronary band (Figure 3.3a). This technique has the disadvantage that the beam is oblique to the cassette, and therefore results in some distortion. It may be useful for assessing fractures, and is helpful in some horses that resent placing the foot in a ‘navicular block’. A parallel 6:1 ratio grid is used if the x-ray beam can be aligned with the grid lines; otherwise a better result is obtained without a grid (Figure 3.3b). This technique may be more practical when there is limited assistance or with difficult horses.

**Dorsopalmar (weight-bearing) view**

A dorsopalmar weight-bearing view is useful for identification and assessment of a sagittal fracture of the distal phalanx, assessment of the width of the distal interphalangeal joint space and lateromedial foot imbalance,
assessment of ossification of the ungular cartilages and identification of changes in opacity of the submural soft tissues. The horse stands weight bearing on the limb, on a flat block, so that the cassette may be placed lower than the solear surface of the foot. For assessment of foot imbalance and the width of the distal interphalangeal joint, both front feet should be on blocks of similar height with the horse weight bearing evenly. A horizontal x-ray beam is centered midway between the coronary band and the ground surface, at the midline of the hoof (Figure 3.4). It should be aligned at right angles to a line drawn across the bulbs of the heel. This ensures a straight dorsopalmar image of the foot. If it is desired to record medial or lateral deviation of the limb distal to the fetlock, the beam should be aligned parallel to the metacarpal region. A 6:1 ratio grid is preferred, but is unnecessary with digital imaging.

**Palmaroproximal-palmarodistal oblique view**

This view is used to give good visualisation of the palmar processes of the distal phalanx, particularly for identification of separation of the laminae of the heel of the foot, or a frontal plane fracture of a palmar process that may not be detectable in any other view.

The horse stands on a cassette tunnel, flat on the floor. The foot to be radiographed is positioned as far caudally under the horse as is consistent with the horse standing flat on the foot. The x-ray machine is placed ventral to the thorax of the horse and the x-ray beam centered between the bulbs of the heel (Figure 3.5). The angle of incidence of the x-ray beam to the cassette is 45–70°, dependent upon the slope of the pastern and the positioning of the foot. The beam is angled so that the image of the fetlock is not superimposed over the palmar processes of the distal phalanx. If the foot is positioned too far forward, it is impossible to avoid superimposition of the image of the fetlock over the foot, especially if the ergot is prominent. This view is obtained without a grid. An alternative technique to obtain this view is described below (see ‘Navicular bone – Palmaroproximal-palmarodistal oblique view’ and Figure 3.64b).
**Other oblique views**

Oblique views of the distal phalanx and hoof wall are often required to assess the hoof wall, lamellar tissue and the distal phalanx. These are particularly valuable if fractures involving the body or palmar processes of the distal phalanx are suspected, and to identify new bone on the dorsal aspect of the distal phalanx, or mineralisation in the dermal laminae. They also help to identify periarticular modelling on the dorsomedial and dorsolateral aspects of the distal interphalangeal joint (Figure 3.40b), or enthesophytes on the middle or distal phalanges, irregularity of the solear aspect of the distal phalanx, fracture of the articular margin of the distal interphalangeal joint, and enthesophyte formation on the navicular bone. Obliquity is determined by one of two factors:

1. An attempt to align the x-ray beam parallel with the line of a fracture.
2. Positioning the x-ray beam so that new bone will be ‘skylined’ (i.e. the beam will form a tangent to the surface of the distal phalanx at the region of the new bone). For this purpose, reduced exposures should be used, and a grid is unnecessary.

Osteophyte or enthesophyte formation on the dorsolateral or dorsomedial aspects of the distal phalanx are often best seen on flexed oblique views, which open the distal interphalangeal joint. The toe of the foot is placed in a navicular block with the sole of the foot approximately vertical, or on a flat block balanced on the toe. Dorsal 60° lateral-palmaromedial oblique (flexed) and dorsal 60° medial-palmarolateral oblique (flexed) views are obtained. A horizontal x-ray beam is used, centered on the coronary band (Figure 3.6).

To highlight the lateral and medial palmar processes using the above technique, dorsal 45° lateral-palmaromedial oblique (flexed) and dorsal 45° medial-palmarolateral oblique (flexed) views respectively should be obtained.

Alternatively, dorsal 45° lateral-palmaromedial (weight-bearing) (Figure 3.7) and dorsal 45° medial-palmarolateral (weight-bearing) oblique images can be used. The horse stands weight bearing on the limb, on a flat block, so that the cassette may be placed lower than the solear surface of the foot. A horizontal x-ray beam is centered 1 cm below the coronary band, midway between the dorsal and palmar margins of the foot. The x-ray beam may also be aligned tangential to a visible defect on the hoof wall. However, the articular margins of the proximal and distal interphalangeal joints are less easy to assess than in the corresponding oblique images acquired with the limb flexed.

Alternatively, to image the palmar processes, the horse should stand on a tunnel containing the cassette. The beam should be angled 45° proximally and centered on the coronary band just behind the midpoint between the dorsal midline and bulb of the heel on the lateral or medial aspect of the foot (Figure 3.8). A lateral 45° proximal-mediodistal oblique image highlights the lateral palmar process, a medial 45° proximal-laterodistal oblique image highlights the medial side. This technique may be preferable in foals; it can be difficult to support a sedated foal with the foot in an upright position. It also permits more consistent angulation of the x-ray beam in foals in order to obtain comparable follow-up radiographs.

The frog clefts should be carefully cleaned and packed to avoid radiolucent artefacts mimicking a fracture.
Figure 3.6 Positioning to obtain a dorsolateral-palmaromedial oblique (flexed) image of the distal phalanx and interphalangeal joints. The use of a ‘Hickman or navicular block’ rather than a flat block may help to stabilise the toe. The x-ray beam (arrow) is centered on the coronary band. An angle of 45° from dorsal highlights the lateral or medial palmar process of the distal phalanx (see Figure 3.15). The dorsal margins of the interphalangeal joints are best imaged with an angle of 60° from the dorsal plane (see Figure 3.14).

Figure 3.7(a) Positioning to acquire a dorsal 45° lateral-palmaromedial oblique (weight-bearing) image of a foot.

Figure 3.7(b) Dorsal 45° lateral-palmaromedial oblique (weight-bearing) image of a normal adult horse.
NORMAL ANATOMY

The front and hind distal phalanges have a similar appearance, but the distal phalanx of the hind feet are slightly narrower mediolaterally than those of the front feet.

Immature horse

The distal phalanx develops from a single centre of ossification, which is present at birth (Figures 3.9a and 3.9b). It continues to enlarge and model until at least 18 months of age. The palmar processes are not evident at birth, and gradually ossify over 12 months, but may not obtain their full length until about 18 months.

Skeletally mature horse

Lateromedial view

The dorsal surface of the distal phalanx is smooth and opaque (Figure 3.10a). The dorsal compact bone is of variable thickness. It may be slightly dorsally convex from the solear margin to the base of the extensor (pyramidal) process, especially in the hindlimbs, and should meet the solear margin at a sharp angle. In horses with a large crena marginis solearis (Figure 3.17a), a radiolucent indentation or a double line may be seen at the junction of these margins (Figure 3.17b). There are considerable variations in the shape of the extensor process, but they are usually bilaterally symmetrical (see Figure 3.18). It is generally accepted that the dorsal hoof wall and the dorsal aspect of the distal

Figure 3.8 Technique to obtain a lateral 45° proximal-mediodistal oblique image of the distal phalanx to skyline the lateral palmar process. The x-ray beam is centered on the coronary band. See also Figure 3.16.
phalanx should be parallel; however, there are a number of studies in both Thoroughbreds and Warmbloods which have demonstrated that the angle of the dorsal aspect of the distal phalanx to the horizontal is often less than the angle of the dorsal hoof wall to the horizontal. The orientation of the hoof wall may be distorted due to poor hoof care, for example an excessively long toe. There is a radiolucent 'halo' between both the hoof wall and sole and the dorsal and distal aspects of the distal phalanx respectively, representing the lamellae and sublamellar dermis (Figure 3.10b). Narrowing of this halo or increase in its opacity may reflect abnormal lamellar epidermis.

The solear surface of the distal phalanx is smooth in outline and is said to be normal if at a 3–10° angle to the sole, sloping proximally toward its palmar aspect. There are significant breed differences, with Thoroughbreds generally having a smaller angle than Warmbloods. The solear canal of the distal phalanx (through which runs the terminal arch of the digital arteries) is seen between the solear surface of the bone and the distal interphalangeal joint. It is seen with a variable degree of clarity, depending on the exposure factors used and the direction of the x-ray beam. It may appear as a very distinct radiolucent zone in the middle of the bone, proximal to the solear surface, but in some bones it is barely evident. Palmar to the solear canal is a sharply defined, smoothly outlined relatively opaque band of bone, the facia flexoria. The deep digital flexor tendon inserts on the palmar aspect (Figure 3.10a).

The articular surfaces of the middle and distal phalanges are reasonably congruous. There is sometimes a smoothly outlined V-shaped notch in the articular margin of the distal phalanx (Figure 3.17c). The middle of the articular

Figure 3.9(a) Slightly oblique lateromedial radiographic image of the foot of a normal foal of approximately 2 months of age. Note the rounded extensor process of the distal phalanx and the rounded shape of the navicular bone. The proximal physis of the middle phalanx is open. The foot shape is more upright than in an adult.

Figure 3.9(b) Dorsoproximal-palmarodistal oblique radiographic image of a foot of a normal foal of approximately 2 months of age. The medial and lateral borders of the distal phalanx are rather poorly defined.
margin of the middle phalanx may be slightly flattened. The width of the joint space is affected by the amount of weight being borne on the foot, and the presence of any effusion within the joint.

**Dorsoproximal-palmarodistal oblique view**

The appearance of the distal phalanx on dorsoproximal-palmarodistal oblique upright pedal and high coronary views is essentially the same (Figure 3.11), although the high coronary image (with the foot stood on a
Figure 3.11 Dorsoproximal-palmarodistal oblique (upright pedal) radiographic image and diagram of a normal adult distal phalanx. Lateral is to the right. A = middle phalanx, B = distal phalanx, C = navicular bone. There is an ill-defined oblique radiolucent line crossing the distal interphalangeal joint laterally, which represents a packing defect.
Chapter 3

The foot

cassette tunnel) does result in some distortion and elongation of the image. The solear margin is well defined, describing a regular curved outline. Some irregularity may be present, especially at the periphery of the vascular channels. The distal phalanges of the hind feet are narrower and have a slightly more pointed outline at the toe than those of the front feet.

A distinct, somewhat blunted V-shaped notch (crena marginis solearis) may be present in the midline in the dorsal aspect of the solear margin of the bone. This is usually present bilaterally, and is variable in size (up to 1.5 cm in depth) (Figure 3.17a and b).

Vascular channels are evident as radiolucent lines, radiating between the solear canal and the solear margin. They are variable in number and width, and may appear to narrow or widen slightly close to the solear margin (Figure 3.19).

The solear canal is extremely variable in its appearance. It is usually an irregular, roughly U-shaped radiolucent canal seen in the centre of the distal phalanx, extending from the level of the distal interphalangeal joint to approximately midway between the joint and the solear margin of the bone. However, variations in shape are common (Figure 3.20a–f).

The distal interphalangeal joint is evident as two distinct lines, the uppermost representing the palmar aspect of the articulation of the distal phalanx with the middle phalanx, close to its articulation with the distal sesamoid (navicular) bone. The lower of the two lines represents a more dorsal portion of the articular surface of the distal phalanx, its exact position depending on the angulation of the bone when radiographed.

Approximately oval-shaped radiolucent areas in the proximolateral and proximomedial aspects of the distal phalanx are seen with variable clarity at the insertions of the collateral ligaments of the distal interphalangeal joint (Figure 3.21). These should not be confused with osseous cyst-like lesions.

Dorsopalmar (weight-bearing) view

In a dorsopalmar (weight-bearing) image (Figure 3.12), the openings of the solear canal are seen as two distinct circular foramina distal to the articular surface of the distal phalanx. The extensor process may be difficult to examine, as it is superimposed over the distal end of the middle phalanx and the navicular bone. The parietal sulci (dorsal grooves) of the distal phalanx are seen as notches on the lateral and medial aspects of the bone. Occasionally these appear as a complete foramen rather than a notch. The solear margin of the bone should be an equal distance from the ground surface of the foot laterally and medially.

This is the best view to assess mediolateral foot balance (see, below, ‘Hoof – Hoof balance’ and Figures 3.12, 3.22 and 3.49). The degree and symmetry of ossification of the ungular cartilages (sidebone) are also best evaluated in this projection, although the extent of dorsal and palmar ossification cannot be assessed.

Palmaroproximal-palmarodistal oblique view

The palmar aspects of the palmar processes of the distal phalanx are seen on either side of the navicular bone (Figure 3.13). The axial and abaxial surfaces have a relatively smooth appearance, although some irregular radiolucencies
Figure 3.12 Dorsopalmar radiographic image and diagram of a normal adult foot. The radiographic image has been collimated so that the medial and lateral extremities of the hoof wall cannot be seen. Medial is to the left. The sole is thicker medially than laterally. Arrows a and b indicate the height between the distal border of the distal phalanx and the ground surface. A = proximal phalanx, B = middle phalanx, C = distal phalanx, D = navicular bone.
within the body of each palmar process are often present. An oval opaque ring may be present in the palmar processes, representing mineralisation in the base of the ungular cartilage (see also ‘Ossification of the ungular cartilages’, below). A lucent ‘halo’ is evident between the hoof wall and the distal phalanx, representing the lamellae and sublamellar dermis (Figure 3.10b).

**Dorsal 60° lateral-palmaromedial oblique and dorsal 60° medial-palmarolateral oblique (flexed) views**

The contour of the extensor process of the distal phalanx is smoothly curved. Depending on the degree of flexion, one of the condyles of the middle phalanx may be partially superimposed over the extensor process. The eminence for the origin of a collateral ligament on the dorsal aspect of the middle phalanx on the opposite side is also seen (Figure 3.14). These eminences tend to be more prominent in heavier breeds of horses and cob types compared with Thoroughbred types. A lucent line courses obliquely across the distal phalanx. This may be either an edge effect created by the superimposition
Figure 3.14 A dorsal 60° lateral-palmaromedial oblique (flexed) image and diagram of the pastern and foot of a normal adult horse. A = proximal phalanx, B = middle phalanx, C = distal phalanx, D = navicular bone.