Diagnostic Imaging of the Equine Thoracolumbar Spine and Sacroiliac Joint Region

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Det er naturlig for alle mennesker å ønske å vite

Aristoteles

Preface

The present work was carried out at the Department of Clinical Radiology, Swedish Agricultural University (SLU) in Uppsala from 1999-2003, and the Department of Large Animal Clinical Science, Norwegian School of Veterinary Science (NVH) is providing my salary for four years.

I wish to express my sincere gratitude towards NVH for letting me stay in Uppsala to fulfil this work, and trying this new way of educating Norwegian PhD students in collaboration with other Universities, and to the Department of Large Animal Clinical Science for providing my salary, help to get funding for some of the work from the insurance company Gjensidige, the Norwegian trotting association (DNT), and others, always sending invitations to departmental parties, and for always making me feel at home when I came browsing through the clinic on a short visit!

I am indebted to the heads of Department of Clinical Radiology, SLU these years, first Kerstin Hansson, and later professor Peter Lord, for the opportunity to stay at the department and become a part of the ”Swedish Radiology Department family”. You have provided me with all I needed to get started: a great attitude towards radiology and research, and an open mind to what we are working with. I have been able to study in my own office, with my own computer, I was allowed to use all facilities, and I have had the loosest reins you can ask for (at least it has felt that way).

The ”Back project”, a never-ending project as long as so many horses suffer from these kinds of problems, was the basis for my research with primus motor *Chris* (PhD Christopher Johnston). His enthusiasm and hard work got our department involved, and together with professor Peter Lord they managed to get funding from Agria Djuförsäkring to carry out this project.

Additionally there are many persons that I would like to thank in particular:

Supervisor *XL* (Per Eksell), for keeping up with me on an ”everyday” basis. Thanks to you I have had the best job possible for the last 4 years, although it must have been tough working with such a stubborn Norwegian! I learned how to love research (almost more than working in the clinic), with a critical mind! You kept me laughing, learning, and let me ask the same questions again and again and again. But most important – you and your dear family became good friends.

Supervisor *Peter* (Lord), for making this all happen! If you hadn’t applied for money, agreed to letting me stay in Uppsala, played sceptic reviewers before submissions, and endlessly corrected my ”swe-nor English”, none of this would have been possible!

Supervisor *Nils Ivar* (Dolvik), for having faith in me, giving all the support you could even if you were 550 km away, and really showing what a great supervisor and person you are in the final and critical phase!

Mieth (Berger), ex ”kombo”, ”turkamerat” and THE playmate in the playground of science. Playing with ideas and being critical together with you got me into this – and with future help from a person like you (both feet on the ground, always) – we can hopefully go on having good times in the forest with the dogs, over a nice meal, or next to the gamma camera!

Ina (Kristina Larsson), ex ”scint-girl” but mentally still there. Your positive attitude (is anything impossible?) and obvious enthusiasm towards almost everything was contagious! But it is hard to match the original. Please do not change!

Charles (Widström), solid as the rock, a magician with the computer, and my bridge to the human nuclear medicine world. Your programs made it a thrill to evaluate scintigrams, your endless patience when explaining physics is amazing, and having you reading the manuscripts made me feel very secure!

Kerstin (Hansson), fellow PhD student & travel mate. To try to learn statistics with you and having your clear thinking, critical but positive mind just a few meters down the corridor has been a pleasure. I would have felt lonely as a PhD student at SLU without you.

All Vets, Techs and Ewa at the Department of Clinical Radiology the past years. By being such great persons with a genuine positive attitude towards life, food and work you have taught me so much, and you are making it very difficult for me to want to move back. And to those of you being directly involved in the examinations of ”my” horses; thank you for all the nice images, and all the ”trying to get them”!

Sören (Johansson) & *Henrik* (Uhlhorn), for dealing with my sometimes morbid wishes (concerning the preparation of specimens) in a superior way. Without all your help things would have become very difficult, and it might not even have been possible!

Karin (R. Holm) & *Chris* (Johnston), to work together with you guys and XL in our Back project group has been a privilege! Together we have managed to be organized, hardworking, and efficient, but at the same time we have managed to have fun, meet several times without too many disturbances, and enjoyed french food and wine twice, in France!

Hege (Kippenes), for advice concerning radiology, computer programs, manuscripts, car import, tax regulations etc, for helping me to teach the Swedes some Norwegian, and for sharing the interest in the Norwegian Cross-country team.

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Bergen Travpark and *Stall Blindheim* in general, *Tini* (Anna K. Milde) in particular. Here is where I learned what it is like to be a ”hestepraktiker”, and here is where I got started aiming for new knowledge. I am grateful *Tini* for having worked together with such an experienced person like you, and for all the advice and support you have given me!

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Mamma (Anne-Lise), *Pappa* (Jan A.), *Gagga* (Gisle) & *Gø* (Gaute) (my family), for all the good times we have had together although we have been living far apart from each other, and for providing a happy childhood to look back on, and serve as a secure base for the future. I am SO privileged to have you!

Johan (Raiend), for patience during all the times I had to work late, for taking care of me in your wonderful way, and for reminding me of what is absolutely most important in life!

Contents

Abbreviations and Glossary

Background	In skeletal scintigraphy; all gamma rays detected by the camera but not emitted from the bone.
Collimator	In radiography; device for restricting the field covered by the primary x-ray beam. In scintigraphy; device to prevent gamma rays that are not oriented with the collimator opening(s) from reaching the detector assembly.
CT	Computed tomography
Film-focus distance	The distance between the x-ray tube focal spot and the plane of the radiographic film.
Grid	In radiography; thin plate consisting of alternating vertical strips of radiolucent and radiopaque (lead) materials which attenuate scattered radiation.
Intensifying screen	Thin plates which are located in the cassette on either side of the film to convert x rays into visible light to which the film is sensitive
IRU	Increased radiotracer uptake
kV	Kilovoltage – the voltage difference between the anode and cathode in the x-ray tube. Determines the penetrating power of the x rays.
mAs	Millampere-seconds – exposure magnitude expressed as the product of current in milliamperes and time in seconds.
MR	Magnetic resonance
PHA	Pulse height analyzer, the energy discriminator in the gamma camera.
PM tubes	Photomultiplier tubes are components in the gamma camera which amplify the electron signal from the photocathode.

Radiography	Practice of making radiographs.
Radiolucency	Degree of blackness of the film, is related to the amount of x rays penetrating the tissue.
Radiopacity	Degree of whiteness of the film, is related to the amount of x rays absorbed by the tissue.
Resolution	Objective measurement of how much detail that can be provided by an image, i.e. the smallest distance that can exist between two objects that allows them to be seen as two separate entities.
ROI	Region of interest, used in quantitative measurements of scintigrams.
ROM	Range of movement, measurement in kinematic analysis.
Scatter radiation	Multidirectional radiation resulting from the interaction of x–rays or gamma rays and an object.
Scintigraphy	Production of images of the distribution of radioactivity in tissues, after systemic administration of a radiopharmaceutical imaging agent.
Sclerosis	Increased opacity of bone.
SI	Sacroiliac
Signal	Gamma rays detected by the camera which are emitted from the bone.
SYM	Symmetry of movement, measurement in kinematic analysis.
Ultrasonography	Imaging of soft tissues using the principle of echography: the variable transmission or reflection of ultrasound waves by tissues of differing densities.

Summary

Many horses show signs of back pain, dysfunction and poor performance likely to be attributed to lesions in the back. The large size of the horse and the inaccessibility of the spine and deeper soft tissue structures make examination and diagnostic procedures difficult and unspecific. Currently judgements about treatment, operation and euthanasia are often based on radiographic and scintigraphic changes in the thoracolumbar spine and pelvis whose true clinical significance is unknown. Similarly, the true pathophysiological significance of so called ”sacroiliac strain” or ”sacroiliac joint injury” and possibly associated increased radiotracer uptake (IRU) in scintigraphy is unknown, with similar implications.

Thirty-three carefully selected asymptomatic riding horses underwent clinical, kinematic, radiographic and scintigraphic examinations to determine changes in the thoracolumbar spine and SI joint region, and to determine if changes from different examinations are related. The radiographic examination included lateral views of the dorsal spinous processes in the thoracolumbar spine and articular processes in the caudal thoracic and lumbar spine. The scintigraphic examination included lateral oblique 60° views of the thoracolumbar spine, and dorsal views of the sacroiliac regions. The level of increased radiotracer uptake (IRU) in the dorsal spinous processes and the SI joints was graded into normal, mild, moderate or severe following specified criteria, and an uptake ratio was calculated for both the dorsal and ventral part of the dorsal spinous processes and the SI joints. The radiographs were evaluated and sclerosis and radiolucencies was graded into normal, mild or more according to specified criteria, and interspinous spaces were denoted as narrow when less than 4 mm wide.

Mild increased radiotracer uptake in the dorsal spinous processes from T13–17 was common, and many horses had coinciding radiographic changes such as sclerosis, radiolucencies and narrow interspinous spaces. Only seven horses had no IRU, sclerosis, radiolucencies or narrow

interspinous spaces (<4 mm). Narrow interspinous spaces was statistically less common cranial to T13 and caudal to T18, and in younger horses. The mean uptake ratio of the dorsal part of the dorsal spinous processes was 0.72 (SD 0.15) and of the ventral part 0.69 (SD 0.12). The results of the semi quantitative evaluation strongly supported the results of the subjective evaluation. To combine the results from the radiographic and scintigraphic examinations with the results from the clinical and kinematic examinations, all results were classified into two categories based on graded results from each examination technique. Twenty-eight horses (28/33) had not more than one change in the examinations performed, according to the classification used in this study.

An anatomic study was done to determine the true location of the SI joint in the dorsal view of the equine pelvis, and it showed that the SI joint was located more lateral than previously described. All horses but one had normal radiotracer uptake in the SI joints and ten horses had normal radiotracer uptake in the area between the tuber sacrale and the SI joint. The mean uptake ratio in the SI joint was 0.53 (SD 0.12). Factors that affect the scintigraphic appearance of the pelvis included attenuation, radioactive urine and muscle symmetry. The thickness of the gluteus medius muscle ranged from 8–11 cm causing 71–82% attenuation of the gamma rays emitted from the SI joint, indicating to severely compromise the sensitivity of the method. The dramatic effect of soft tissue attenuation was demonstrated by calculating a corrected SI joint ratio; the mean corrected SI joint ratio was 2.14 (SD 0.50). Assessment of muscle symmetry and awareness of radioactive urine ventral to the SI joint region is essential for a correct subjective evaluation of the SI joints. Any situation with difference in muscle mass between the left and right sides of the pelvis will give a false impression of increased radiotracer uptake on the side with lesser muscle mass, and radioactive urine located ventral to the SI joint may create a false impression of IRU.

Sammendrag

Ømhet og smerte fra ryggen og kryssregionen hos hest er ikke uvanlig og påvirker helsetilstanden og prestasjonsevnen hos sportshester generelt, og ridehester spesielt. Vanskeligheter med å stille en eksakt diagnose ved en vanlig klinisk undersøkelse har gjort at bruken av diagnostiske hjelpemidler ved undersøkelser av rygg og kryss har øket i omfang. Røntgen, skjelettscintigrafi og ultralyd er de modalitetene innen bildediagnostikken som egner seg best til dette formålet. Selv ved utstrakt bruk av disse metodene kan man ikke alltid identifisere årsaken til ryggproblemer hos hest. Dette medfører blant annet at avgjørelser om behandling, operasjon eller avliving kan baseres på røntgen- eller scintigrafiske funn i ryggen eller bekkenregionen som man egentlig ikke kjenner den kliniske betydningen av. De ulike modalitetene gir informasjon om de forskjellige vevstypene som f.eks. ben, muskulatur og leddbånd. På normale hester er det bare utseendet av torntappene i ryggen som er beskrevet ved hjelp av røntgen, og hvor man fra tidligere studier vet at normale hester kan ha en rekke røntgenforandringer. Det er først når man kjenner variasjonen av både røntgenfunn og scintigrafiske funn hos tilsynelatende normale individer at det blir mulig å tolke undersøkelsesresultatene hos hester med kliniske symptomer fra rygg og kryss.

I denne avhandlingen er 33 normalt fungerende halvblods ridehester undersøkt med en grundig klinisk undersøkelse, røntgen og scintigrafi. Dessuten ble disse undersøkelsene komplettert med en kinematisk undersøkelse. Opptaket av den radioaktive isotopen ble registrert og gradert etter en firedelt skala: normalt opptak, mildt, moderat og kraftig forøket opptak. Forekomst og grad av sklerose og nedsatt beintetthet samt forekomsten av smale mellomrom mellom torntappene fra T10–L2 ble også registrert. Dessuten ble det gjort en anatomisk studie for å bestemme lokalisasjonen av ileosakralleddet i et scintigram, slik at det scintigrafiske utseendet av dette leddet kunne registreres. Til slutt ble effekten av faktorer som påvirker bildekvaliteten og bildetolkningen undersøkt. Den normale variasjonen i det scintigrafiske utseendet av torntappene i ryggen hos hest ble beskrevet og sammenlignet med funn som ble gjort ved hjelp

av røntgen. Dessuten ble det scintigrafiske utseendet av ileosakralleddet og området mellom ileosakralleddet og tuber sakrale beskrevet. Forut for de bildediagnostiske undersøkelsene ble en grundig klinisk undersøkelse gjennomført. Dette for å sikre at hestene som inngikk i studien ikke hadde kliniske funn som kunne tilbakeføres til smerter i rygg og kryss. Dessuten ville vi registrere eventuelle variasjoner av kliniske funn på tilsynelatende normale hester.

Et mildt øket opptak av den radioaktive isotopen i torntappene fra T13–17 var et vanlig funn hos disse hestene, samt at mange hester hadde røntgenforandringer som sklerose og nedsatt beintetthet. Mange hester hadde smale mellomrom mellom torntappene, men det var signifikant mindre vanlig foran T13 og bak T18 og hos yngre hester. I ileosakralleddet hadde alle hestene unntagen én et normalt opptak av radioisotopen, og i området mellom ileosakralleddet og tuber sakrale var det tilsynelatende stor variasjon i opptaket. Faktorer som sterkt påvirker det scintigrafiske utseendet av bekkenregionen er attenuering av den overliggende muskulaturen, muskelasymmetri og om det er radioaktiv urin igjen i urinblæren ved undersøkelsen. Disse faktorene må tas hensyn til for å kunne gjøre en korrekt bedømmelse av ileosakralleddet. Tykkelsen av muskulaturen som ligger over ileosakralleddet ble målt på alle hestene og varierte fra 8–11 cm som attenuerer 71–82% av gammastrålene fra det underliggende benet. Dette betyr at sensitiviteten for metoden påvirkes betydelig, og at det ved muskelasymmetri må tas hensyn til ulik grad av attenuering når to sider skal sammenlignes.

For å kombinere funnene fra de bildediagnostiske undersøkelsene med de kliniske funnene og resultatene fra den kinematiske studien ble alle resultater endelig klassifisert i en todelt skala basert på de graderte resultatene fra hver enkelt undersøkelse. Av de 33 hestene som inngikk i studien hadde 28 hester ingen eller én forandring med de oppsatte kriteriene for tilstedeværelse av forandringer i enten den bildediagnostiske, kliniske eller kinematiske undersøkelsen. Fordi hestene var selektert etter veldig strikte kriterier så viste resultatene også at selv et avvikende resultat i en eller flere av undersøkelsene ikke nødvendigvis påvirker prestasjonen.

Introduction

The following introduction consists of a section about the anatomy of the thoracolumbar spine and pelvis, an introduction to the problem of diagnosing back pain and dysfunction, a presentation of all the diagnostic imaging modalities used in veterinary practice, and an introduction to general interpretation principles of scintigraphic images and radiographs. The sections about anatomy and diagnostic imaging modalities has been included to give a brief background to the challenge of diagnostic imaging of the equine back. As some of the described modalities have not been used in this thesis, either because they are not currently in use in horses, or they are not so suitable for the evaluation of the equine back, an explanation to why was considered appropriate.

Anatomy and function of the spine and sacroiliac region

The Spine

The equine vertebral column consists of seven cervical, eighteen thoracic, six lumbar and five sacral vertebrae (Figure 1). The structural and functional unit of the vertebral column is the vertebral motion segment. A vertebral motion segment consists of two adjoining vertebrae and the connecting soft tissue structures. Each vertebra consists of a body, one dorsal, two transverse, and four articular processes (Figure 2)

The vertebrae are firmly joined through the articulations with a series of long and short ligaments and musculotendinous structures that provide stability to the vertebral column. The principal functions of the vertebral motion segment are segmental protection of the spinal cord and associated nerve roots, support for weight bearing and soft tissue attachment, and provision of segmental flexibility.

The size and shape of these processes vary throughout the spine, as they are developed to fit the function of each anatomical region. The articular processes are large and wide apart in

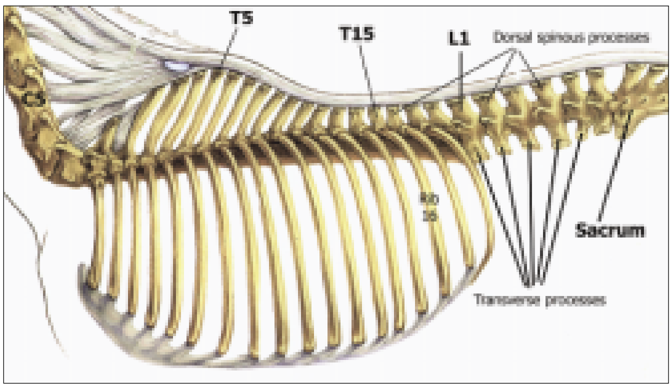


__Figure 1:__ The equine vertebral column consists of seven cervical, eighteen thoracic, six lumbar, and five sacral vertebrae. The sacrum is usually formed by the fusion of the five sacral vertebrae, and described as a single bone. (Reprinted with permission from Equistar Publications, Ltd, Marysville, Ohio, USA. Copyright 1996)

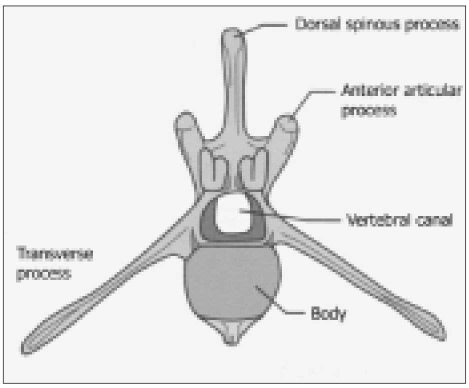


__Figure 2:__ A transverse schematic drawing of a vertebra. Each vertebra consists of a vertebral body, one dorsal, two transverse (left and right), and four articular processes (anterior left and right and posterior left and right).

the neck, reduced in size and much closer together in the dorsum, and larger and interlocking in the lumbar region (Figure 3). Dorsally, the articular processes create bilateral synovial articulations, the intervertebral joints.

Dorsally in the midline each vertebra has a dorsal spinous process. These incline caudad in the cranial part of the thoracic spine, and in the caudal part the inclination is craniad until the sacrum. The anticlinal vertebra, that with a vertical dorsal process, is usually T15 (Figure 1). The lumbar vertebrae have long horizontal transverse processes, and the sacral transverse processes are fused to form the wings and lateral parts of the sacrum. Synovial joints sometimes develop between the transverse processes of the fourth and fifth lumbar vertebrae, and they are constantly present between the fifth and sixth vertebrae, and between the sixth and the wings of the sacrum (1, 2).

On either side of the spinous processes is a groove whose floor is formed by the lamina of the vertebral archus and articular processes. The groove contains the deep muscles (M. multifidus, M. spinalis), and the more superficial muscles of the spine (M. longissimus) that stretch along the whole spine (Figure 4). The os ilium is primarily covered by the gluteus medius muscle, which partly originates from the longissimus lumborum via a strong fascia.

A series of long and short spinal ligaments contributes to vertebral column stability. The nuchal ligament in the cervical vertebral region continues as the superficial supraspinous ligament in the thoracolumbar vertebral region and joins the tips of the associated spinous

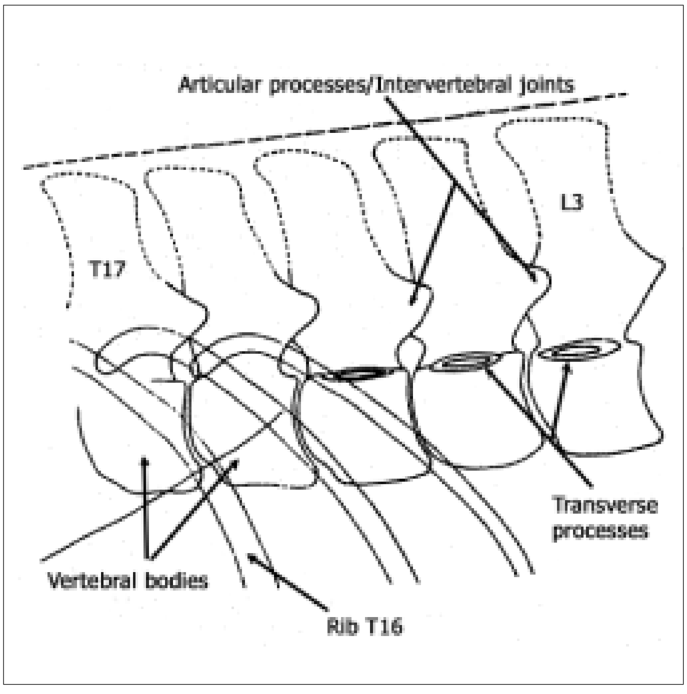


Figure 3: *Diagram showing the articular processes/intervertebral joints in the caudal thoracic and cranial lumbar spine. (Illustration modified from Veterinary Radiology 1979 (20) 140-147)*

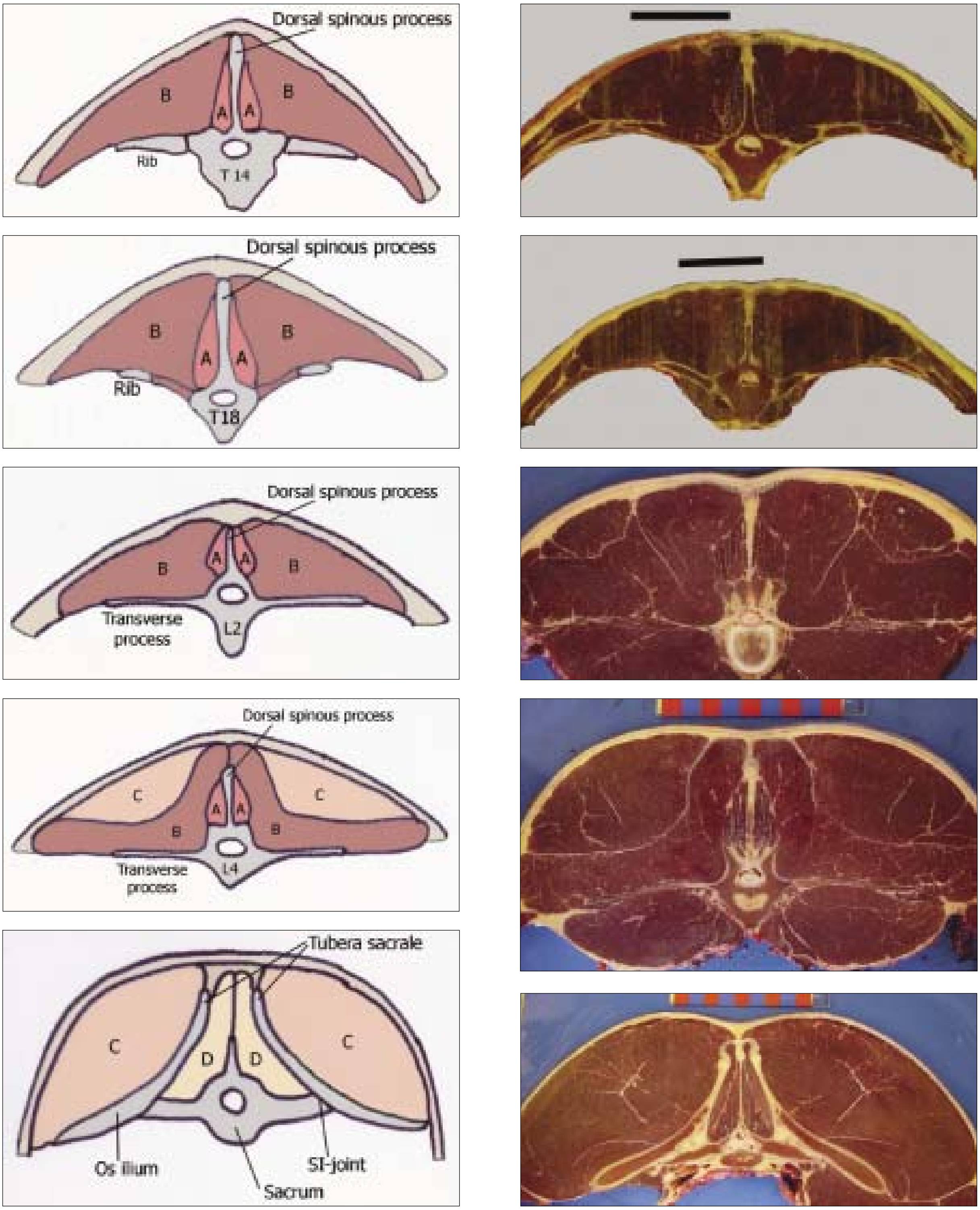


Figure 4: *Schematic drawings of transverse sections of the spine from T14 and caudally to the level of the sacroiliac joint with corresponding pictures of transverse sections of a frozen specimen. Musculus (M.) multifidus and M. spinalis (A) are a long series of segmental muscles, which lie along the sides of the dorsal spinous processes of the vertebrae from the neck to the sacrum. Caudally they are continued as the sacrocaudalis dorsalis medialis muscles (D). M. longissimus (B) extend from the neck to the ilium and sacrum. M. gluteus medius (C) originates in the aponeurosis of the M. longissimus lumborum in the cranial lumbar region, and is a large muscle covering the gluteal surface of the os ilium, and the greater part of the lateral wall of the pelvis. The black ruler in two pictures measures 10 cm, and the ruler in the remaining pictures is divided into red and blue sections of 2 cm each.*

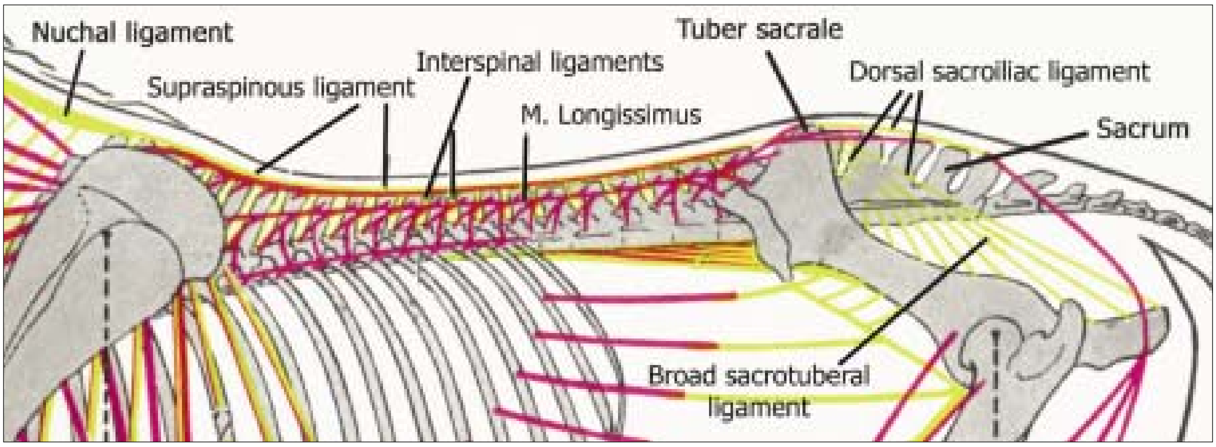


Figure 5: *Schematic drawing of the bones, long muscles, and ligaments of the equine back. M. longissimus is the largest and longest muscle group in the body extending from the neck to the ilium and sacrum. The supraspinous ligament extends from the occipital bone to the sacrum, and the interspinous ligaments extend between the spines of continuous vertebrae. (Illustration modified with permission from Nickel/Schummer/Seiferle, Lehrbuch der Anatomie der Haustiere, Bd1)*

processes (Figure 5). The short spinal ligaments interconnect individual vertebrae protecting the spinal cord and providing segmental vertebral stability. Interspinous ligaments connect adjacent dorsal spinous processes (Figure 6). Fibres in the dorsal portion of the interspinous ligaments are ventrocaudal continuations of the supraspinous ligament into the interspinous space (2).

Spinal movement occurs in three planes, allowing flexion-extension, lateral bending, and axial rotation. The amount of movement that is possible varies along the vertebral column depending on the size, shape, and orientation of the intervertebral discs, articular processes, dorsal spinous processes, transverse processes and ligaments. Kinematic measurements of spinal movement in live horses on a treadmill have shown little movement in the thoracolumbar spine at the trot. At the walk more lateral bending, flexion/extension and axial rotation has been measured, and at the canter the predominant movement is flexion/extension (3–5). Horses moving around freely can display larger ranges of movement in the back when they play around, bucking and rearing, or when they graze or scratch themselves, compared to the movement on a treadmill.

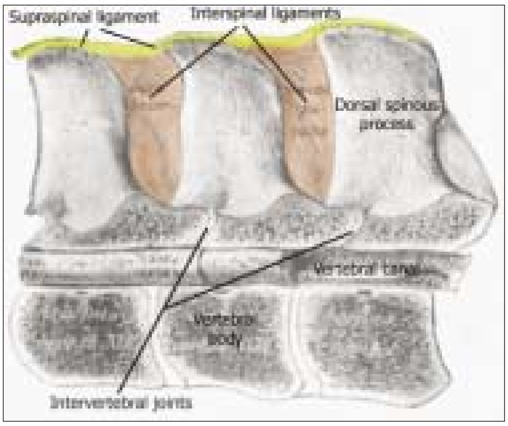


Figure 6: *The interspinous ligaments consist of fibres directed obliquely ventrally and caudally. The fibres in the dorsal portion of the interspinous ligaments are ventrocaudal continuations of the supraspinous ligament into the interspinous space. (Illustration modified from Sisson and Grossman's, The Anatomy of the Domestic Animals)*

The sacroiliac region

The left and right sacroiliac (SI) regions for the purpose of this thesis were defined as the SI joint, tuber sacrale, the three caudal lumbar vertebrae, and the area between the tuber sacrale and the SI joint.

The SI joint is a synovial joint between the auricular surfaces of the wings of sacrum and ilium (6). The joint is located ventral to the iliac wing, which is covered by the gluteus medius muscle (Figure 7). The joint attaches the sacrum to the pelvis to form the pelvic ring, and forces originating from the pelvic limbs to propel the body forward are transmitted through this joint (7).

The joint has a close-fitting and well-developed joint capsule, which is surrounded and reinforced by the ventral sacroiliac ligaments (Figure 8). The dorsal sacroiliac ligament is a strong band, which is attached to the tuber sacrale and the summits of the sacral spines. Another part of this ligament is a triangular thick sheet, which is attached cranially to the tuber sacrale and adjacent part of the medial border of the ilium dorsal to the great ischiatic notch, and ventrally to the lateral border of the sacrum. It blends ventrally with the broad sacrotuberal ligament, and caudally with the caudal fascia (Figure 5).

The size and contour of the SI joints varies, but the shape has been described as a sock in

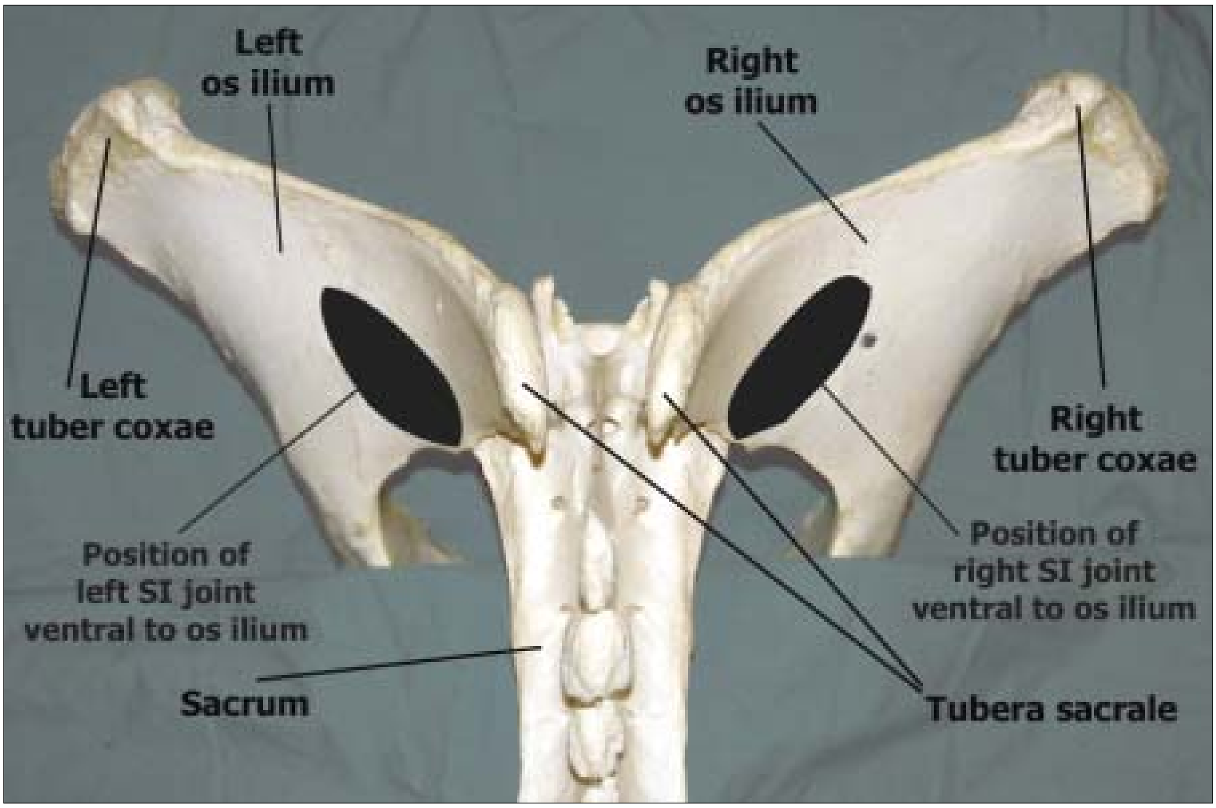


Figure 7: *Dorsal view of the equine bony pelvis.*

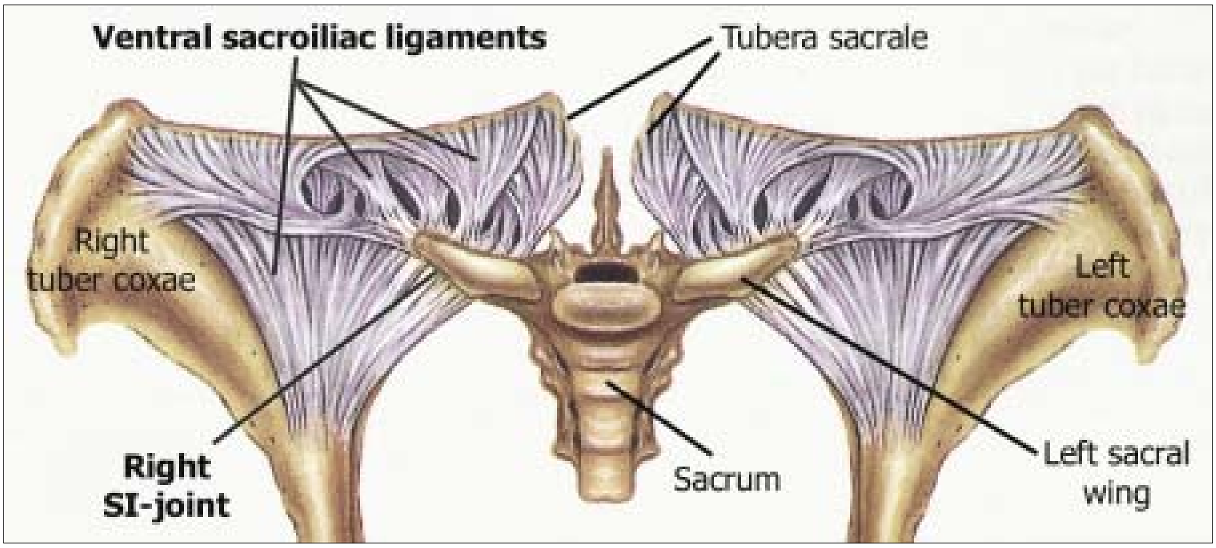


Figure 8: *Ventral view of the equine bony pelvis to illustrate the ventral sacroiliac ligaments. (Reprinted with permission from Equistar Publications, Ltd, Marysville, Ohio, USA. Copyright 1996)*

the majority of horses, with the convex border facing caudally and ventrally (6). There is little or no movement in this joint at the walk and trot, but a substantial degree of axial rotation has been found between the sacrum and tuber coxae at the canter (8). The movement in the SI joint is still a controversial subject, and the kinematics of this area is unclear. The joint is difficult to access by palpation and manipulation, and intraarticular injections with local anaesthetics are difficult to perform.

Introduction to the problem of diagnosing back pain and dysfunction

Back pain, dysfunction and poor performance in horses have been known for a long time. These problems occur mainly in horses used for riding, and they seem to be more prevalent in middle aged to older horses. Lesions in soft tissue structures and bony parts of the thoracolumbar spine and pelvis may be the cause of clinical signs, but it can be difficult to localize the specific origin of the problem. The equine back is a diagnostic challenge to any veterinarian because the large size of the horse and the inaccessibility of the spine and deeper soft tissue structures make diagnostic procedures difficult and unspecific. Sometimes the clinical signs may even be caused by factors outside the horse such as the saddle, rider or poor schooling of the horse. Currently clinicians, surgeons, lawyers and insurance companies are making judgements based on radiographic and scintigraphic changes whose true clinical significance is unknown. Consequently horses may be treated, operated, euthanised, horse sales may be cancelled, and owners of insured horses may be compensated for a false reason. Similarly, the true patophysiological significance of so called ”sacroiliac strain” or ”sacroiliac joint injury” and possibly associated increased radiotracer uptake (IRU) in scintigraphy is unknown, with similar implications.

The thoracolumbar spine

Some of the first reports about different aspects of back pain in the horse were published in 1975 (9, 10). An increasing interest in competitive and pleasure riding resulted in more awareness of back problems, and the subject has since that time been discussed in a number of studies. These studies have covered:

Radiographic technique: The procedures for the best quality radiographic examination of the thoracolumbar spine in standing horses and horses under general anaesthesia have been described (11, 12). A description of normal radiographic anatomy has been presented, and ”incidental” radiographic abnormalities in apparently normal horses were described. A high incidence of narrow interspinous spaces with the summits of the dorsal spinous processes in contact with each other called ”crowding” or ”overriding” of the dorsal spinous processes was found, and the term ”kissing spines” became common to describe the condition. Changes other than crowding and overriding of the dorsal spinous processes were few. A grading system to quantify the radiographic findings in the dorsal spinous processes in each horse was developed (13, 14). This grading system provided the basis for the interpretation of radiographs of dorsal spinous processes done today. No other radiographic studies of the spine of normal horses have to our knowledge been reported since then.

Radiographic and scintigraphic findings in horses with clinical signs: The horses examined in the reports have all been clinical patients, but the selection of the horses varied. ”Kissing spines” or radiographic changes such as sclerosis, narrowing of interspinous spaces, periosteal reactions, and occasionally cyst-like lesions/radiolucent areas, mainly in the area from T13–18 have been described (10, 14–20). Scintigraphy was introduced to veterinary medicine in 1975, and has since then become increasingly used (21, 22). Today skeletal scintigraphy is widely used in equine practice, but although many papers describe the technique, general interpretation principles, and common findings (16, 18, 23–28), scintigraphic studies of normal horses have been limited (29–31). By combining the sensitive method of scintigraphy with radiography one hoped to identify active processes in the bone, assuming these were more likely to cause pain (22). In some studies of clinical patients a relationship between IRU and radiographic lesions has been described, but no conclusions were made about which relationships were most common, or which lesions were most likely to cause pain (15–20).

Ultrasound examination: Many authors have described the examination procedures of the supraspinous ligament, articular processes/intervertebral joints, transverse processes and the lumbosacral junction (32–36). These procedures may be used routinely and offer primarily information about structural changes in soft tissue (32–36), but also abnormalities in the bony surface such as irregularities (enthesopathy), fragmentation and discontinuations can be detected, especially in the more superficial bony structures (32, 33, 35). However, all identified ultrasonographic abnormalities have been compared with the ideal ”normal” anatomic appearance (32–36), and some deviations from the perfect anatomic appearance may not be a potential cause of pain. Unfortunately the equine back is composed of an enormous number of structures, some only partly, others not accessible to ultrasound at all. In a practical situation it is not feasible to ”scan the back” by ultrasound, looking for abnormal changes anywhere, because of the very long examination time. But a directed examination toward specific structures of potential interest indicated by other examinations can be done.

Post mortem findings: Macroscopic post mortem studies of horses without known complaints from the back have demonstrated a series of bony lesions in the thoracolumbar spine (37–39). The lesions have been described as vertebral osteophytes, impingement of dorsal spinous processes, fusion of lateral joints, and degeneration of intervertebral discs. Most of these horses have been thoroughbreds, and the lesions have been called pathologic or degenerative changes suggesting that they may be of potential clinical importance. One study also describes histopathologic changes in ligaments, intervertebral joints and intervertebral discs in horses with ”kissing spines” (40). Many of the changes such as lesions in the intervertebral ligaments, intervertebral discs and intervertebral joints seen in horses with ”kissing spines” were thought to be caused by unphysiologic repeated ventroflexion of the back (40). The clinical relevance of similar changes in other horses is unknown.

Biomechanical aspects: The movement in the thoracolumbar spine has been described by measuring dorsoventral flexion and extension, lateral bending and axial rotation. The initial reports used specimens of dead horses, followed by in vivo studies of horses with bone-fixated pins in the vertebrae to develop a protocol for this type of measurements. Today a protocol using reflector markers placed on the horse's skin while the horse is moving on a treadmill and high speed cameras record the movements of the markers, has been proved useful with high repeatability (3–5, 8, 41–44). The reference range of movement in the back in a careful selected material of asymptomatic riding horses has not been determined, and neither has the relationship between kinematic data and clinical, radiographic and scintigraphic changes.

Clinical examination: A routine examination with particular attention to the radiographic examination was proposed by Jeffcott in the initial report (10). The clinical examination should include a clinical history, examination at rest and exercise, local anaesthesia to locate painful areas followed by a radiographic and/or a scintigraphic examination (17, 18, 45, 46). Later papers and a literature review have described more aspects of the clinical examination, specific suggestions to what should be included in the clinical examination, differences in results between breeds, and the validity of palpation in horses with an assumed back problem (10, 15, 47–50). These papers describe the procedure of examination and clinical findings in horses with a potential problem, but a discussion about the results of a clinical examination of horses without apparent back problems is lacking.

With few exceptions, little attention as been paid to the characteristics of the spine of asymptomatic horses. As radiographic lesions have been found in normal horses, scintigraphic uptake might be expected also. It is known from the literature of the human back, and a few studies on horses, many so-called degenerative changes of the spine may be present in asymptomatic individuals, and their presence should not be interpreted as the cause of the problem (13). Therefore this thesis is directed at the study of the radiographic and scintigraphic characteristics of the back of asymptomatic horses.

The sacroiliac joint

The diagnosis ”sacroiliac luxation” was first reported by Rooney (51, 52). In the initial reports a theoretical explanation for a lameness called ”stifle-lameness” was given (52–54), and the diagnosis ”sacroiliac arthrosis” was based on post mortem macroscopic examinations of the pelvis (53). In a biomechanical description of causes of back pain the diagnosis ”sacroiliac arthrosis” was regarded as a cause of so-called ”stifle-lameness” (55), and a similar clinical syndrome has also been called ”chronic sacroiliac strain” (10, 14). In one textbook (56) the syndrome ”subluxation” of the sacroiliac joint or ”sacroiliac strain” is characterized by chronic intermittent lameness, based on the initial studies in the seventies. A newly published textbook (57) offers a discussion proposing that several different diagnoses be fitted into one: ”sacroiliac joint injury”, where the description of clinical signs include hind limb lameness, back pain and poor performance. A golden standard for the diagnosis ”sacroiliac arthrosis”, ”chronic sacroiliac strain” or ”sacroiliac joint injury” is still lacking, even if gross pathologic evidence of degenerative changes in the SI joints has been used as proof for the disease (53). Pathologic studies of normal horses have revealed the same types of so-called degenerative changes (6, 38), and only in four horses with chronic sacroiliac damage, histopathologic evidence of osteoarthrosis in the sacroiliac joints have been described (58).

The potential relevance of sacroiliac pain in horses with lameness and poor performance has resulted in many studies. In the eighties the basic morphology, morphometric features and histology of the SI joints was studied, together with studies about the radiographic examination of these joints (6, 58–62). Material consisting of 41 horses was selected to describe the normal morphology, morphometric features and histology of the SI joint (6, 59, 62). The age of these horses ranged from equine fetuses to adult horses up to 15 years old. Six horses of various breeds were representing the adult riding horse between 6 and 15 years of age. The normal shape of the joint, spur formation at the joint margins, and the development of age related changes such as discoloration of the joint surfaces and cleft formation without articular cartilage around the joint margins were described. Differences in morphometric measurements, but otherwise similar post mortem appearances to what was seen in the normal horses described earlier (6, 59, 62) was found in a study of horses with clinical suspicion of ”sacroiliac arthrosis” because of low grade hind limb lameness and elimination of other problems (58). Therefore they suggested (58) that arthrosis in the SI joints was not nearly as prevalent as suggested before (53). Radiography and linear tomography of the SI joint revealed only unspecific and inconsistent findings (14, 60, 61).

In recent years several studies have been directed towards ultrasound and scintigraphy of the SI joint. According to Denoix (32) it is possible with ultrasound to evaluate the bony surface of the caudomedial articular margins of the joint with a rectal approach, as well as the ventral sacroiliac ligaments, although the entire joint is not possible to examine for anatomical and technical reasons. Remodelling of the articular borders, altered echogenicity of the ventral ligament, and decreased joint space were changes described with this approach. Tomlinson et al. has described a systematic mapping of the normal equine pelvis using ultrasonography transcutaneously and per rectum (63), validated by using computed tomography (CT), magnetic resonance imaging (MR) and measurements of frozen cadaver slices. This study was followed by a report about ultrasonographic abnormalities in horses with ”sacroiliac pain” (64). No abnormalities were seen with a rectal approach, and changes in the dorsal sacroiliac ligament were registered in all horses with ”sacroiliac pain” (64). The results from the ultrasonographic studies differ, and correlative histopathologic evidence of degenerative changes in the SI joints is lacking.

With the increasing availability of scintigraphy this method became recommended as a diagnostic tool for sacroiliac joint lesions (23, 65). The first report specifically about scintigraphy of the SI joint described abnormal changes by showing scintigrams pointing out areas with IRU and using an asymmetry index (66). In addition abnormal findings in the SI joints have been described by showing scintigrams in horses with back pain (15, 19, 20). The lack of, or the vague anatomic description of the location of the SI joint in these studies made it important to identify the SI joint’s location to improve the reliability of scintigraphic images. The most recent studies of the equine SI joints have described the scintigraphic appearances in normal horses (31), and two different groups of clinical patients (67). In these studies the anatomic location of the SI joints was determined by using a radiograph of one horse superimposed on a scintigram, and then the joint was subjectively identified for the quantitative analysis. A subjective descriptive analysis of horizontal profiles superimposed over the SI joint regions and a quantitative analysis was performed. The results showed an overlap between normal horses and clinical patients with pain in the SI joint region suggesting that making a diagnosis based on scintigraphy alone is difficult.

In contrast to the positive attitude about the value of scintigraphy in the diagnosis of SI joint disease in horses, the subject in human medicine is controversial. In human medicine the sacroiliac joints originally were considered important in patients with back pain, especially in patients with spondylo-arthropathies. In the 80's scintigraphy was considered a sensitive method to detect sacroiliitis, and a large number of studies have been published about this specific examination (68–81). Despite all the work done on the human side to evaluate scintigraphy for this type of problem, there are still many different opinions about the interpretation, and the value of scintigraphy in sacroiliac joint syndrome has been questioned (82). Due to high sensitivity, low specificity and low predictive values, human hospitals in Sweden and Norway today rarely use scintigraphy in patients with back pain for the diagnosis of sacroiliitis/sacroiliac joint syndrome (83–89).

Previous scintigraphic studies have adapted interpretation principles from human nuclear medicine, and differences in anatomy and size between man and horse have not been discussed in veterinary literature. The much larger size of the horse, and the much greater muscle mass cause poor resolution and contrast in images of the spine and pelvis, and have made anatomic location of certain structures difficult. The effect of soft tissue attenuation in veterinary literature has been suggested not to be significant (90), is not mentioned or ignored in other studies (15, 20, 23, 56), and is discussed only briefly in recent literature (28, 31, 67). Two pilot studies combined with a clinical case with a pelvic fracture demonstrated very clearly the dramatic effects of soft tissue attenuation in dorsal views of the equine pelvis: decreased sensitivity, resolution and image contrast (Figures 9–11) (91, 92). The equine pelvis is covered by the

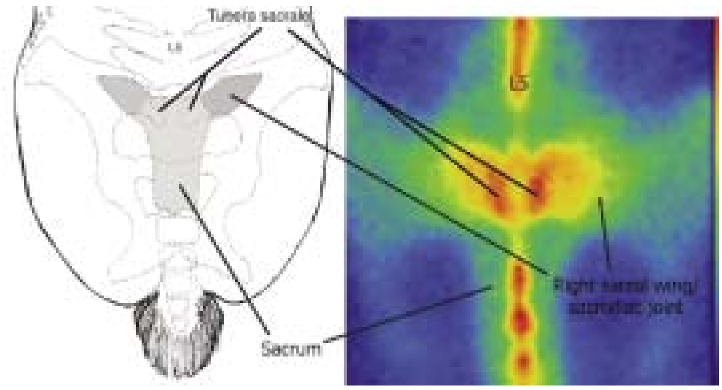


Figure 9a: *To the left a drawing of a pelvic specimen including the bony pelvis and all surrounding musculature. To the right a dorsal view of the specimen; a normal scintigram of the equine pelvis centred over the spine.*

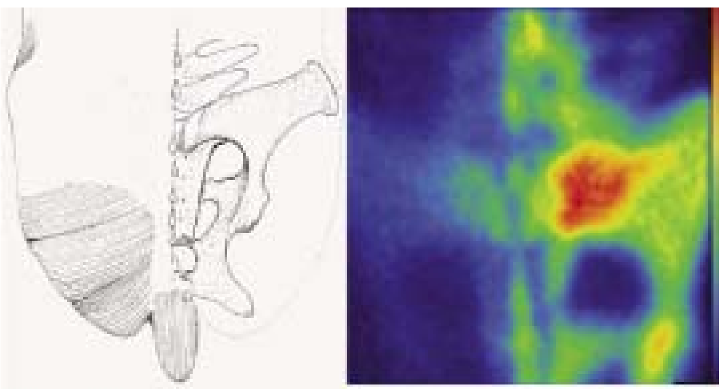


Figure 9b: *To the left a drawing of the same specimen after the pelvic musculature on the right side has been removed. To the right a dorsal view of the specimen with removed muscle on the right side demonstrating the dramatic effect of soft tissue attenuation. After the muscles on the right were removed the radiotracer uptake in the bone is much more visible.*

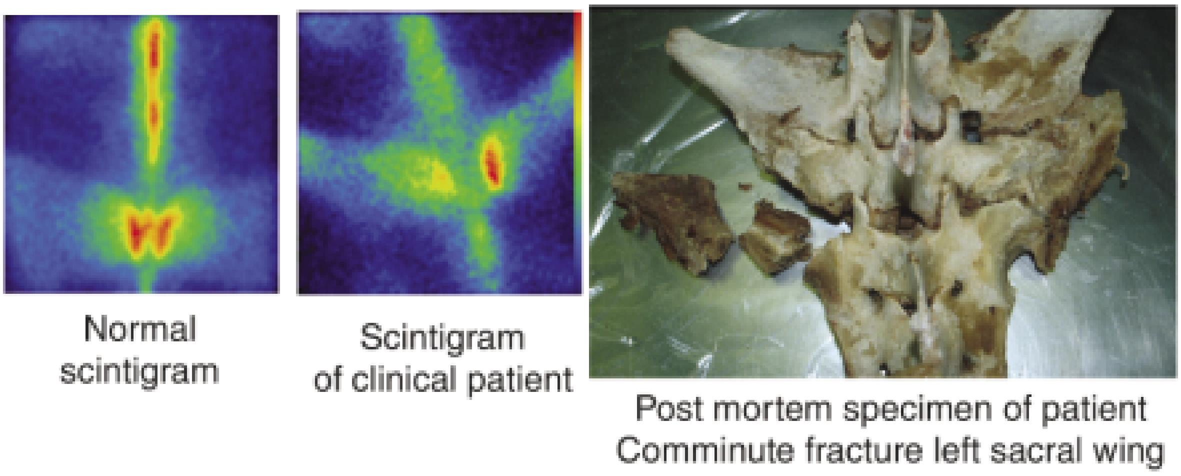


Figure 10: *The scintigram to the left is a dorsal view of the pelvis with no abnormal findings. The scintigram to the right is a dorsal view of the pelvis with obvious asymmetry between the left and right sides. The uptake in the left SI joint is severely increased compared to the usual uptake in this joint, but not relative to the other structures in the image. The horse had a comminuted fracture through the left sacral wing. Although the fracture was more than one week old at examination, the severe uptake at the fracture site does not appear as severe in the image, because of the attenuation of the radiation by the thick gluteal muscles.*

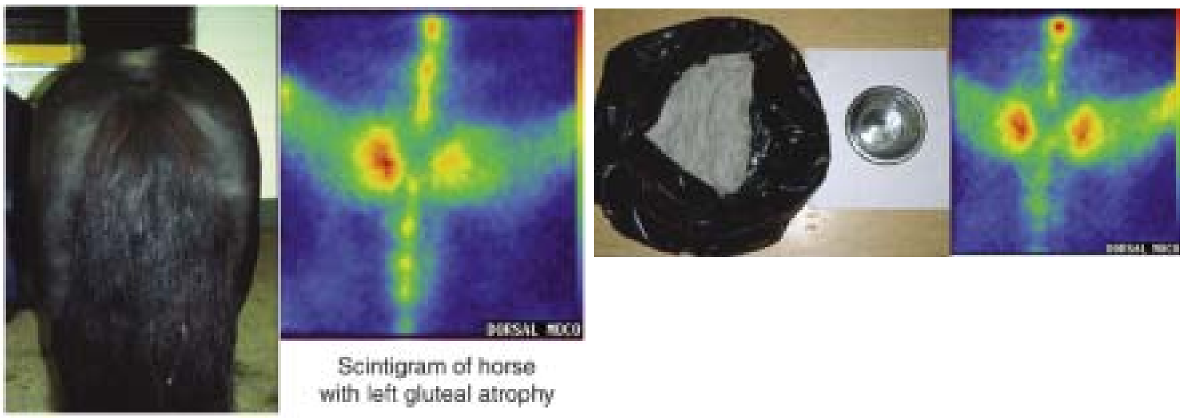
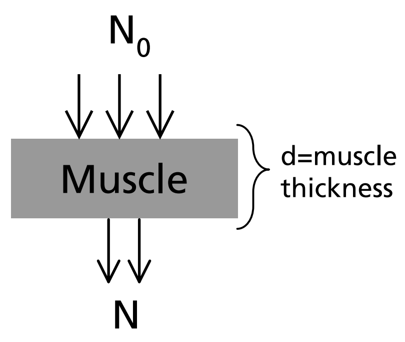


Figure 11: *The scintigram to the left is a dorsal view of the pelvis of the horse photographed from behind. The horse had obvious atrophy of the left gluteal muscles, and a moderate increased radiotracer uptake in the left tuber sacrale. To simulate replacing the wasted muscle mass a layer of paper soaked in water was placed over the left gluteus medius muscle. A repeated dorsal view of the pelvis demonstrated symmetric uptake in both tubera sacrale and the rest of the pelvis. Without knowing that this horse had marked muscle atrophy, the radiotracer uptake in the left tuber sacrale would have been interpreted as moderately increased.*

large gluteal musculature, and the mass attenuation coefficient for muscle with gamma rays of energy 140 keV is 0.1492 cm^2/g (93). Overlying muscle will cause significant attenuation of the gamma rays emitted from the bone (Table 1). The muscle mass also increases the amount of scattered radiation, which affects the contrast, resolution and statistical validity of the image.

Table 1: *The calculated proportion of attenuated gamma rays (1-N) with energy 140 keV at different muscle thickness. D is the muscle thickness in centimetres, N is the proportion of gamma rays that penetrate the muscle, ρ is the density of muscle and the mass attenuation coefficient is 0.1492.*



$$N=N_0e^{-\rho(\mu/\rho)d}$$

d(cm)	ρ	Mass ATT. COEFF	N (%)	1-N (%)
4.46	1.04	0.1492	50.05	49.9
5	1.04	0.1492	46.03	54.0
8	1.04	0.1492	28.90	71.1
10	1.04	0.1492	21.19	78.8
11	1.04	0.1492	18.14	81.9
12	1.04	0.1492	15.54	84.5
15	1.04	0.1492	9.75	90.2
20	1.04	0.1492	4.49	95.5

The effects of soft tissue attenuation and specific imaging problems caused by renal secretion of the radiotracer must be considered when the evaluation of the SI joint is done. Most of the radiopharmaceutical not taken up by the skeleton is excreted by the kidneys and is in the urinary bladder at the time of skeletal scintigraphy. For the same reasons mentioned for the spine, the scintigraphic evaluation of the SI joint in this thesis is directed towards determining the characteristics of the joint in asymptomatic horses.

Diagnostic Imaging modalities

Radiography

Radiography is the oldest imaging modality used in veterinary medicine. It is based on the ability of X rays to penetrate and interact with matter. X rays are photons, like light, but with a much shorter wavelength and higher energy. When x-ray photons of sufficient energy pass through a patient, some photons are absorbed, some are scattered, and others pass through unchanged. A radiograph is an image of the number and distribution of the x-ray photons that pass through the patient unchanged and strike the cassette, which contains radiographic film. The film is placed between a pair of intensifying screens. The screens are flat thin plates which emit light through fluorescence when they are exposed to x-ray photons. The blackness of a radiograph is dependent on the amount of light exposing the radiographic film and thus the number of x-ray photons absorbed by the intensifying screen. The film is darkened in proportion to the number of x-ray photons penetrating the patient. Bone absorbs more than muscle and other soft tissue and creates a white shadow.

To penetrate thicker parts of a horse high energy X rays are necessary produced by powerful generators. In equine practice outside animal hospitals portable equipment is often used, and these are not powerful enough to produce x rays that can penetrate the thickest parts of the horse. A disadvantage with high energy x rays is the increased amount of scattered radiation which is produced, some of which also exposes the film and reduces the contrast. Even if horses are examined under general anaesthesia, anatomic features of the horse hinders multiple projections and full visibility of many parts of the internal organs and skeleton. The image quality of the thicker parts of the horse can be improved in different ways. A grid will increase the contrast by reducing the scattered radiation on the film. Fast intensifying screens reduce the resolution, but enable thicker parts to be radiographed with the same exposure. Wedge filters reduce uneven exposure of the dorsal spinous processes caused by the varying thickness of the muscles on either side. Ultra fast films enable the highest exposure values possible, resulting in shorter exposure times and less motion unsharpness in the examination of standing horses.

Linear tomography

Linear tomography is a way of making radiographs of an area of interest, which normally is partially or completely obscured by shadows of overlying or underlying structures. The x-ray tube is mechanically linked by a bar to the cassette holder. Motion unsharpness is created by using long exposure times, and a motor moves the tube linearly around a fixed pivot point and the cassette moves in the opposite direction. Structures above and below the pivot point are blurred, but everything in the horizontal plane of the pivot point is sharp. This technique for use in horses was described by Jeffcott in 1983 using an expensive custom built unit (60, 61). The sacroiliac area was considered the most important region to visualize because of its anatomic inaccessibility and potential clinical importance. Horses were placed in lateral or dorsal recumbency under general anaesthesia. The usefulness of this method as a standard technique is limited by the unique and expensive equipment, and later studies revealed other limitations. The procedure was time consuming, and non-specific findings such as increased joint space, which was sometimes associated with pelvic asymmetry, were the only findings associated with ”sacroiliac strain” (14, 58). Thus linear tomography provided little useful information in relation to the cost and difficulty of performing the examination.

Diagnostic ultrasound

Medical sonography uses sound wave echoes to create images, thus is a diagnostic imaging modality that does not use electromagnetic radiation. The ultrasound beam is transmitted into the tissue by means of piezoelectric crystals housed in a transducer, which is also the echo receiver. The echoes are generated whenever the sound beam crosses a boundary between structures of differing acoustic impedance. Acoustic impedance depends on both the sound velocity and the density within a tissue. The greater the difference in acoustic impedance at the boundary, the greater intensity of the returning echoes. Highly reflective boundaries such as between soft tissue and bone or gas result in a high amplitude echo displayed a bright signal, and precludes display of tissue information deep to the reflecting surface. In soft tissues different degrees of absorption, scatter and reflection of the ultrasound beam create different degrees of echogenicity enabling different tissues and lesions in them to be seen. The frequency of the ultrasound beam determines the resolution of the image, and the depth of penetration. Lower frequencies produce images with less resolution, but enables display of deeper structures. In equine practice ultrasound is widely used to evaluate the reproductive organs, tendons, joints, ligaments and surface of bones. Any soft tissue structure to a certain depth can be evaluated, but in practice the method is very dependent on the skills and experience of the operator, and examinations of large and complex areas such as the whole back are extremely time consuming. Ultrasound is described as being helpful to evaluate superficial structures of the spine such as the supraspinous ligament, dorsal sacroiliac ligament, and deep structures like the articular processes, the SI joints, and intervertebral discs (32, 33, 35, 45, 63, 64). The information gained from the deeper structures such as the articular processes and the SI joints represents only a part of the examined structure. A complete examination of the superficial structures of the back is technically possible, but only a directed examination towards specific structures is useful in a clinical situation. In this thesis ultrasound was only used to measure muscle thickness. Partly because the procedure was considered to be of limited value when only parts of a structure could be examined, and because it would be practically impossible to examine the whole thoracolumbar back.

Computed tomography and Magnetic resonance imaging

The physical principles applied in computed tomography (CT) and magnetic resonance (MR) image formation includes the use of a computer to acquire signal data from various image planes, and reconstruct the data into cross-sectional images of the body to allow visualization of the internal structures without superimposition. Data are typically acquired as series of slices of information along an axis of the animal's body.

CT imaging uses x-ray absorption principles to create an attenuation map, similar to a radiograph. The mechanisms of MR image acquisition are different from any other imaging modality, although the MR scanners physically appear similar to CT scanners. The MR scanner includes a strong magnet, transmit and receive coils, gradient magnets, a computer and a table. The superior image contrast in MR images between the different soft tissues, fat, and water is caused by the difference in the magnetic characteristics, and behaviour of the hydrogen protons bound in these various tissues.

There are important limitations for the use of CT and MR in examinations of horses today. The equipment used for CT and MR imaging is very expensive, and is mainly developed for the examination of human patients. Modification of the equipment is necessary to allow examination of horses. Still, due to the size limitations of the horse, only the head, the cranial neck, and the extremities can be evaluated. Unfortunately, the physical properties of these techniques limit the size of the examined objects, and it is questionable if it ever will be possible to examine the equine spine and pelvis with either of these methods.

Scintigraphy

Scintigraphic images are produced by injecting a patient with a radioactive isotope prior to the examination. A special detector called a gamma camera is used to detect gamma radiation produced by the decay of the nuclei within the patient.

The gamma camera

The gamma camera is a scintillation detector that functions as both a counter and a position detecting device. The gamma camera is composed of the following components: collimator, detector, positional circuitry, pulse height analyzer, scaler, and recording device (Figure 12).

A. *Collimators*

The collimators in nuclear medicine allow only the gamma rays from the patient, which are parallel to the collimator openings to reach the detector in the camera. Only these photons contribute to the image. Other photons, which do not contribute to the image, are absorbed by the collimator. The most common collimator design is the parallel hole collimator, which consists of multiple parallel openings of identical shape (usually round or hexagonal) perpendicular to the crystal surface (Figure 13). The septa between the holes in the collimator are usually composed of a high molecular weight material (usually lead), which will discriminate photons not perpendicular to the collimator openings. The collimator selection (high resolution, pinhole, diverging and converging collimators), will affect the image size and the spatial resolution of the camera system (Figure 14).

The low energy general purpose (LEGP) collimator is a general purpose collimator with mid-range resolution and sensitivity.

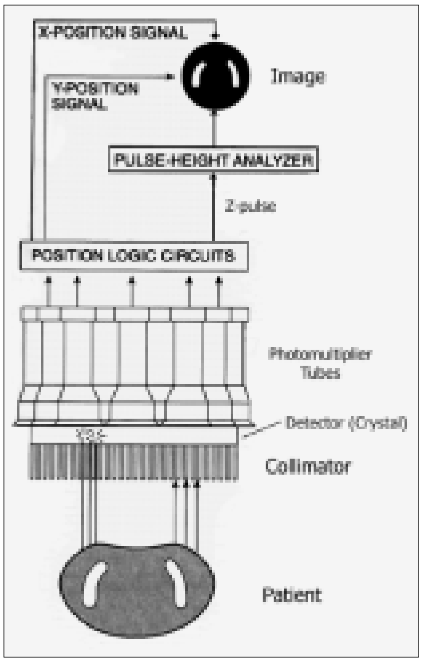


Figure 12: *The basic components of a gamma camera. (Illustration modified from Berry/Daniel, Handbook of Veterinary Nuclear Medicine)*

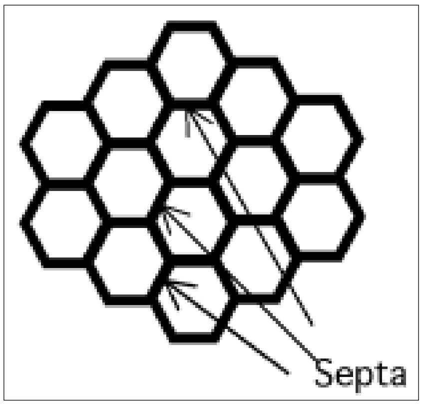


Figure 13: *Transverse view of a parallel hole collimator with hexagonal openings.*

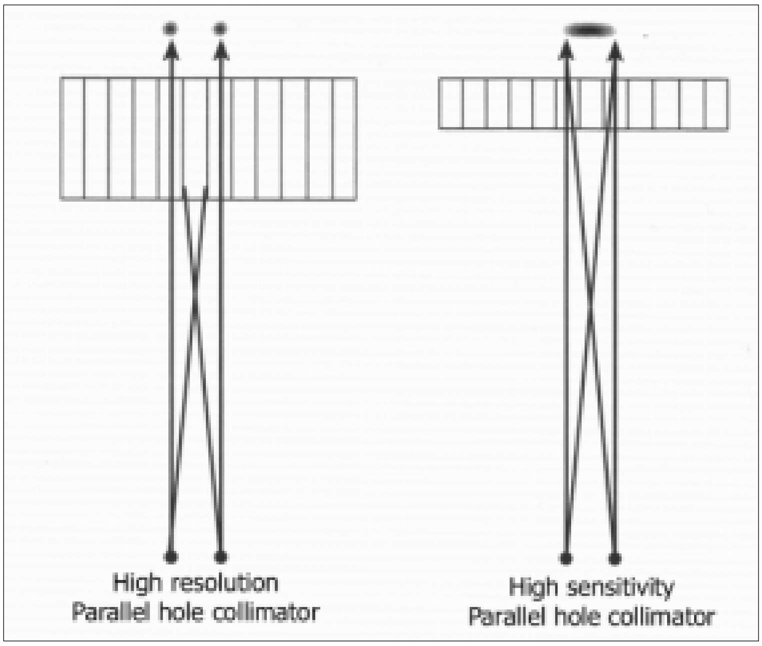


Figure 14: *The difference between a high resolution parallel hole collimator and a high sensitivity parallel hole collimator. (Illustration modified from Berry/Daniel, Handbook of Veterinary Nuclear Medicine)*

B. *The Crystal*

The scintillation detector of the gamma camera is a thin (7–8 mm), large thallium activated sodium iodide crystal. The crystal converts the energy from the gamma ray passing through the collimator into visible light, which is transferred to the photocathode of the photomultiplier (PM) tubes. The photocathode will produce electrons in numbers that are proportional to the intensity of the light flash. As the number of electrons produced by the photocathode is to small to generate an electrical signal, the PM tubes amplify the number of electrons.

C. *Positional circuitry*

The part of the camera that determines the point of absorption of the gamma ray in the crystal, thus determining where in the patient the gamma ray was emitted from is called the camera's positional circuitry. The light flash from the crystal is detected by the array of PM tubes, and the PM tubes closest to the light flash receive the greatest signal intensity. The amount of light received by each PM tube is related to the distance from the PM tube to the point of absorption in the crystal. Increasing the number of PM tubes in a camera will improve the ability of the positioning circuitry to determine the point of photon absorption in the crystal. Camera spatial resolution has been significantly improved by decreasing the size and increasing the number of PM tubes. Typically older cameras (more than 15 years old) had only 19 PM tubes. A significant improvement in resolution occurred by increasing the number to 37, and many currently produced cameras have 61 PM tubes.

D. *Pulse height analyzer*

The light flash converted into electrical signals, registered and amplified in the PM tubes is then received by the pulse height analyzer. The pulse height analyzer is an energy discriminator that limits the recorded signal to a specific energy range, which is called the energy window. Those signals with energy above or below a preset energy window will be rejected. The centre of the energy window is matched to the photo peak energy of the desired radionuclide i.e. 140 keV for Technetium (^{99m}Tc). By increasing the width of the window, the acceptance zone around the photo peak is widened. Scattered radiation has lower energy than the photo peak, and the detection of scatter is reduced by centring the window of acceptance over the photo peak of the desired radionuclide. Narrow windows of 5–10% of the photo peak energy provide the best resolution by excluding more scatter radiation but result in decreased count rate and longer acquisition times. A 20% window centred on the photo peak energy is a commonly used compromise.

E. *Scaler*

The number of gamma rays (signals) having an energy pulse acceptable by the pulse height analyzer are recorded by the scaler or counter. This count information can be used by the camera to produce analogue images, or the output of the gamma camera can be sent to a computer. Image acquisition may be either time based or count based.

F. *Recording device*

The output of the gamma camera consists of three analogue signals; x, y and z. The x and y signal carry the positional information for each event and z carries energy information. The camera position signal (x, y) must be changed from an analogue to a digital form before they can be processed by the computer. These signals pass through an analogue-to-digital converter which converts the signal into discrete electrical units. This information contained in the digital image can be displayed, manipulated and stored.

Skeletal scintigraphy

Skeletal scintigraphy is one of the most commonly performed scintigraphic imaging procedures in veterinary medicine, first described in 1975 (21). Skeletal scintigraphy is considered to be highly sensitive for lesions in bone (26–28). The most commonly used isotope in skeletal scintigraphy is ^{99m}Tc, because of its many suitable properties such as: short half life (physical half life 6 hours), low price, easy access, and biological inertness. Prior to administration the isotope is bound to a radiopharmaceutical, a bone tracer substance, such as methylene diphosphonate (MDP) or hydroxymethylene diphosphonate (HDP). The bone tracer is delivered to the bone in proportion to the blood flow, and accumulates in proportion to the metabolic activity of the bone (27). Modelling of bone causes greater uptake of the bone tracer, and occurs with lesions in the bone such as trauma, infection, neoplasia, and in specific physiologic processes such as adaptation to stress and growth. The physiologic or pathological process being imaged during the so called bone phase is the local rate of bone tissue modelling, but a complete skeletal scintigraphic examination is divided into 3 imaging phases, including: vascular (phase 1), extra cellular or soft tissue (phase 2) and the bone phase (phase 3). The diphosphonates are rapidly cleared from the blood and excreted through the kidneys producing highly radioactive urine. According to the directions for use of DRN 4355 Technescan®HDP by Mallinckrodt* only 10% of the initial ^{99m}Tc-HDP activity remains in the blood in humans after one hour. About 50% of the injected dose of HDP is retained in the skeleton 24 hours after administration, but because of the short half life of ^{99m}Tc the amount of radiation is minimal, and the horse can be released to the owner. Pharmacokinetic studies in horses of radiopharmaceuticals have not been found in the literature.

Skeletal scintigraphy of horses requires high amounts of radioactivity (4.500 MBq/500 kg) compared to the amounts used in small animal practice (450 MBq/30 kg), or human medicine (750 MBq/adult). High levels of radioactivity require special attention to the exposure of imaging personnel, and radioactive horses should only be kept in specially assigned stables. Scintigraphic examinations should only be done when a medical indication is present, and all work should be based on the As Low As Reasonably Achievable (ALARA) principle regarding exposure of personnel.

Image acquisition of the bone phase in equine practice is done by placing the horse in front of a gamma camera, which is mounted on a gantry, which moves the camera to different parts of the horse, and is either dynamic or static. It is a dynamic study when a sequence of a preset number of images (or frames) is acquired during a certain acquisition time. During a static study one image is acquired until a preset number of counts or time has been reached. Scintigraphic images have low resolution compared to radiographs. The intrinsic resolution of the gamma camera is limited by the spatial circuitry, crystal thickness, number of PM tubes, and the pulse height analyzer. However the major causes for poor resolution and contrast are extrinsic factors such as the choice of the collimator and collimator-patient distance.

* *Mallinckrodt Medical (UK) Ltd., Nuclear Medicine Division. 11, North Portway Close, Round Spinney – Northamptom NN3 4RQ*

Distance: The best resolution can be achieved when the patient is near the surface of the collimator. Horses are large animals and significant distances between bone and the surface of the collimator are unavoidable in some parts of the animal.

Movement: Blurred images are produced when the patient moves during the acquisition. Long acquisition times improve count statistics and resolution, but increases the risk of motion unsharpness. Motion correction programs (94) or acquisition under general anaesthesia may help to reduce this problem.

Scattered radiation: As the gamma rays from the bone interact with the overlying soft tissue to produce scatter radiation, the contrast is reduced depending on the amount of muscle overlying the examined area. Scattered radiation from ^{99m}Tc is only registered by the gamma camera when the energy level falls within the energy window. It has been reported that with the standard 20% photo peak energy window approximately 30% of the counts in a ^{99m}Tc image may originate from scattered photons (95). The scattered radiation that is registered by the gamma camera reduces contrast and resolution in the image, without adding any information.

Interpretation principles of radiographs and scintigrams

Subjective evaluation

Subjective evaluations are based on standard principles of interpretation and previous experience of the observer. Currently one textbook in veterinary nuclear medicine exists (96), but chapters about skeletal scintigraphy used in horses have now been included in recent issues of at least two textbooks (28, 65). In addition many papers describe basic interpretation principles, and specific interpretation of various diseases (15, 16, 23, 26, 66, 67, 90, 97–100). In the optimal scintigram of the equine spine the individual vertebra can be clearly distinguished. Regions of bone close to the skin surface such as the apices of the spinous processes, particularly at the withers, the tuber coxae and tuber sacrale appear with higher intensity than adjacent bone structures because of less soft tissue attenuation (16). In the optimal dorsal view of the pelvis and caudal lumbar spine it is difficult to separate the individual vertebrae of the lumbar spine. The deep pelvic bones are visible and the dorsal spinous processes and tubera sacrale appear with the highest activity in the image. It has been described recently that the appearance of the tubera sacrale and SI joints is affected by age (31), and empirical information has also demonstrated a marked variation of the scintigraphic appearance of the pelvis.

Scintigrams are digital images which can be evaluated in numerous different colour displays, including the grey scale, and a wide range of tools (computerized post processing) can be used to help the evaluation (Figure 15 and 16) (27). Different colour displays have been developed for different types of examinations to highlight certain parts of the study. Which colour display to use in skeletal scintigraphy depends mainly on the observer's personal preference, although the continuous grey scale is traditionally popular for skeletal scintigraphy.

The choices of post processing have traditionally also been based on personal preference, and on the available computer software. With modern computers and software it is possible to use a variety of filters, change colour scale, draw regions of interest (ROIs) and profiles in the images in an easy and user-friendly way. Filters reduce noise in the images (101), changing the colour scale can improve contrast and increase the sensitivity (102), and ROIs and profiles enables comparison of uptake in different areas. No written guidelines for a standard evaluation procedure in skeletal scintigraphy exists, and this lack may be a potential source of high interobserver variability.

Radiographs are in general high resolution images, although radiographs of thicker parts of the horse have less resolution and contrast compared to radiographs of the extremities. Fast film/screen combinations, much scatter radiation, and use of thick grids contribute to the poorer resolution. The observer of radiographs evaluates bone density, structure and topography. The interpretation of radiographs should follow the principles, which are described and illustrated in a large number of textbooks.

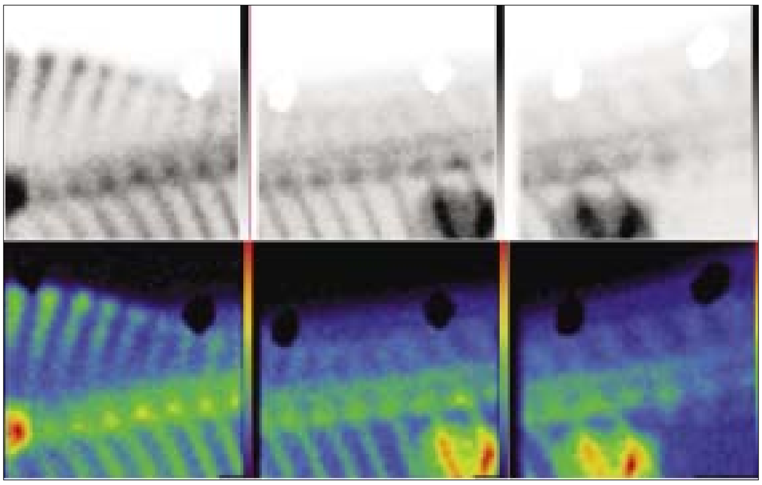


Figure 15: *These normal scintigrams are left lateral 60° oblique views of the thoracolumbar spine (cranial is to the left) displayed in two different colour scales, the continuous grey scale and the blue, green and red colour scale.*

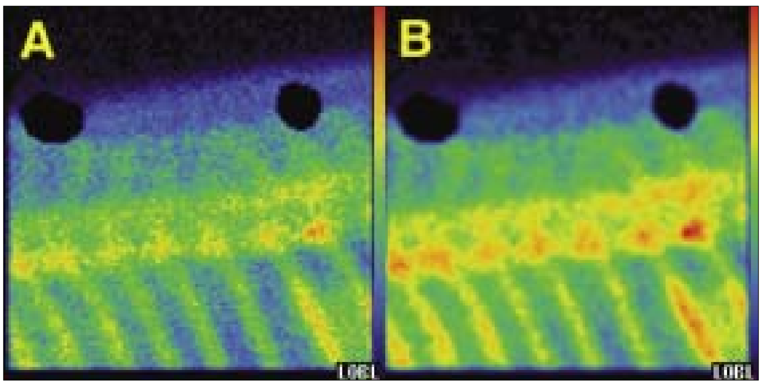


Figure 16: *These normal scintigrams are left lateral 60° oblique views of the saddle region (cranial is to the left). The scintigram to the left is the raw image (A), and a 9-pixel mask smoothing operation has been applied on the image to the right to decrease noise in the image (B).*

Quantitative measurements

The digital scintigraphic image allows measurements of radiotracer uptake providing sensitive and objective ways of quantifying skeletal metabolism. Quantitative measurements of radiolabelled diphosphonate uptake have been widely applied to a variety of clinical problems in human medicine, and have proved most valuable in the diagnosis and follow-up of patients with diffuse metabolic bone disease. It also plays a role in monitoring therapeutic response, and several different techniques are currently in use for quantifying diphosphonate uptake by the skeleton (103). The choice of technique depends on the clinical problem being investigated, and also on available software and expertise. The simplest way of quantifying the uptake in an area of diseased bone (the area of interest or lesion) is to express the mean pixel count in this area as a ratio of the mean pixel count in an area of comparable normal bone (reference area) or soft tissue, acquired, when possible in the same image. Uptake ratios are usually obtained from scintigrams by drawing a ROI around the area being studied, or by obtaining a profile over it. The mean pixel count in the ROIs, or the counts at different levels of the profile is then obtained from the computer. By expressing the number of counts in an area as mean counts per pixel in a ROI, differences in size or location of ROIs can be corrected for. The ideal control region, or reference, according to human literature is a matched contralateral area of normal bone, or an adjacent normal vertebra if the abnormality is spinal (103). Which reference to use in equine skeletal scintigraphy has not been discussed in the veterinary literature.

In veterinary textbooks the value of quantitative bone scanning has been discussed briefly (28), and quantitative assessments of scintigrams have been described in several reports (19, 22, 30, 31, 66, 67, 97). Because it would be convenient to have an objective way to evaluate scintigrams, the value of quantitative results in equine skeletal scintigraphy should be investigated. The possibility to detect statistically valid information in equine skeletal scintigraphy may be compromised by the large muscle mass covering the bone in some areas, and the relative short acquisition times needed to reduce motion unsharpness.

List of papers

1. C Erichsen, P Eksell, C Widström, K Roethlisberger Holm, C Johnston, P Lord
   Scintigraphic evaluation of the thoracic spine in the asymptomatic riding horse
   Vet Radiol Ultrasound 2003. 44: 330–338
2. C Erichsen, P Eksell, K Roethlisberger Holm, P Lord, C Johnston
   The relationship between the scintigraphic and radiographic evaluations of the thoracic spine in asymptomatic riding horses
   Submitted 2003
3. P Eksell, C Erichsen, C Johnston, K Roethlisberger Holm
   Clinical, kinematic, radiographic and scintigraphic relationships in the back in asymptomatic riding horses
   Submitted 2003
4. C Erichsen, M Berger, P Eksell
   The scintigraphic anatomy of the equine sacroiliac joint
   Vet Radiol Ultrasound 2002. 43: 287–292
5. C Erichsen, P Eksell, C Widström, M Berger, K Roethlisberger Holm, C Johnston
   Scintigraphy of the sacroiliac joint region in asymptomatic riding horses – scintigraphic appearance and evaluation of method
   Accepted for publication 2003, Vet Radiol Ultrasound

Aims of thesis

The principle aim of this thesis was to describe scintigraphy and radiography of the thoracolumbar spine and scintigraphy of the sacroiliac joint region in ”normal” horses, and to combine these methods of examination with clinical information and kinematic data. Asymptomatic horses were examined, focusing on answering the following questions:

Thoracolumbar spine

1. What is the reference range of scintigraphic findings in the equine thoracolumbar spine?
2. Are both scintigraphic and radiographic findings present in the thoracolumbar spine of asymptomatic horses, and if, and how are they coincided?
3. Is it possible to perform quantitative analysis of scintigrams of the thoracolumbar spine, and how are the results related to the subjective evaluation?
4. Is it possible to relate radiographic and scintigraphic changes with clinical and kinematic results to improve the diagnostic accuracy in the evaluation of the equine thoracolumbar spine?

Sacroiliac joint region

5. Where is the equine SI joint located in a scintigram of the dorsal view of the pelvis, and what is the normal scintigraphic appearance of the SI joint?
6. What affects the scintigraphic appearance of the SI joint region?
7. Is it possible to perform quantitative analysis of the radiotracer uptake in the SI joint and does it improve reliability?

These questions were derived from the following hypothesis: There is a spectrum of scintigraphic and radiographic changes in the dorsal spinous processes of the thoracolumbar spine and scintigraphic changes in the SI joint in asymptomatic horses that can be identified, graded and classified to improve the diagnostic accuracy in the evaluation of the equine back and pelvis.

Material & Methods

Thirty-four asymptomatic active riding horses were carefully selected with all genders, ages, and common fields of use of the adult riding horse represented (Table 2).

Table 2: *Age, bodyweight, height, gender and use of the analyzed horses*

Use		Age		Weight (kg)		Height (cm)		Gender		
		Mean	Range	Mean	Range	Mean	Range	Geldings	Mares	Stallions
Dressage	14	9,1	6–15	605	507–685	167	160–174	7	5	2
Show jumping	16	8,5	5–13	578	495–636	166	160–172	7	8	1
Eventing	3	11,3	8–15	590	526–640	167	158–172	1	2	0
TOTAL	33							15	15	3

These horses underwent a thorough clinical and a kinematic examination, a scintigraphic and radiographic examination of the thoracolumbar spine, and a scintigraphic examination of the SI joint region. All horses were given 160 mg furosemide intravenously approximately one hour prior to examination. Due to technical problems one horse had to be excluded from the analysis.

Lateral oblique 60° scintigrams of the thoracolumbar spine and lateral radiographs of the dorsal spinous processes in the thoracolumbar spine and articular processes in the caudal thoracic and lumbar spine were obtained. All scintigrams and radiographs were evaluated by two observers together to produce a consensus opinion. A subjective evaluation of radiotracer uptake, sclerosis, radiolucencies, proliferations in the articular processes, and width of the interspinous spaces from T10 to L2 was for the purpose of this thesis based on criteria modified from general interpretation principles. The width of all interspinous spaces was measured with a digital calliper, the intensity of the radiotracer uptake was graded into mildly, moderately or severely increased, and the distribution of sclerosis and radiolucencies was denoted normal, mild or more. Quantitative measurements of the radiotracer uptake in the dorsal spinous processes were done with a dedicated computer program. An uptake ratio between the uptake in the dorsal and ventral part of the dorsal spinous processes and a reference area (rib 16) was calculated and compared with the results of the subjective evaluation.

The results from the clinical examination were reactions to palpation and a description of the gait during the lunging (ordinal data). In the kinematic examination flexion/extension and lateral bending angular movement patterns, including the range of movement (ROM) and symmetry of movement (SYM) for the vertebrae T10, T13, T17, L1, L3 and L5 were measured (continuous data). The number of times a horse was categorized as a possible outlier in the ROM and SYM was recorded. For the comparative analysis of the four examination techniques all results were classified:

1) Clinical data were classified into presence of palpation (moderate or severe reaction) or not, lunging abnormalities (problems maintaining the gait correctly, short hind limb stride or stiffness) or not.
2) Kinematic data were classified into possible outlier more than twice or not.
3) Radiographic data were classified into coinciding sclerosis (more), radiolucency (more) and narrow interspinous space (<4mm wide) or not.
4) Scintigraphic data were classified into presence of IRU (moderate or severe) or not.

Plastic tubes filled with radioactivity were attached to bony specimens, and the pelvis of a standing horse was simulated by placing each specimen on table under the gamma camera. The plastic tubes enabled localization of specific landmarks and the articular margins of the SI-joint in the scintigrams of the specimens. The same landmarks could then be used to locate the SI joint in dorsal views of the pelvis in live horses. The radiotracer uptake in the SI joints (area 1) and the area between the SI joints and the tubera sacrale (area 2) in the asymptomatic horses was evaluated. The intensity of radiotracer uptake in both areas of interest was compared to the uptake in the ipsilateral tuber sacrale, and graded into normal or mildly, moderately or severely increased. A semiautomatic computer program was developed and used to calculate the uptake ratio between the SI joint and a reference area, the ipsilateral tuber sacrale. The thickness of the gluteus medius muscles dorsal to the os ilium was measured with ultrasound to calculate the magnitude of soft tissue attenuation, and a corrected SI joint ratio was calculated based on these measurements. A lateral view of the urinary bladder was included in the scintigraphic examination to determine the location of, and the amount of radioactive urine within the bladder. The effect of urinary bladder activity on the apparent activity of the SI joints was evaluated by comparing the grading of IRU and uptake ratio in horses with and without radioactive urine in the bladder ventral to the SI joint region.

Main Results

Thoracolumbar spine

Dorsal spinous processes

Many horses had IRU in the dorsal spinous processes, most frequently in T13–17. The reference range should include all horses with only mild IRU in the dorsal spinous processes from T10–L3. The continuous blue, green and red (BGR) colour scale was more sensitive than the continuous grey scale, and all horses with IRU in the continuous grey scale were also detected in the BGR colour scale. Only few dorsal spinous processes were graded differently in the different colour displays (0.63–2.15% of the total number of observations). The total number of horses with no IRU in the dorsal spinous processes was the same when comparing the evaluation of raw and filtered images in both colour displays, and in only one observation was the grading of IRU one level higher in the filtered image than in the raw image. Thus the filter process used in this study had no effect on the detection of IRU in the dorsal spinous processes.

Nine horses had no IRU (9/33), seventeen horses (17/33) had no sclerosis, twenty-one horses (21/33) had no radiolucencies, and eleven horses (11/33) had all their interspinous spaces more than 4 mm wide. Combining all results, seven horses (7/33) were completely negative, with no IRU, sclerosis, radiolucencies, or narrow interspinous spaces (<4 mm wide). The majority of scintigraphic and radiographic findings in the remaining 26 horses were mild, and mainly localized to T13–18. Five horses had dorsal spinous processes with both moderate and severe grades of IRU, with coinciding narrow interspinous spaces or sclerosis and radiolucencies. The mean width of all the interspinous spaces ranged from 4.4–14.3 mm. Presence of narrow interspinous spaces (<4mm wide) was significantly associated with increasing age, and the measured width of each of the interspinous spaces T11–12, T15–16, T16–17 and L1–2 decreased significantly with increasing age of the horses. The mean width of each interspinous space was lowest from T13–18, and <u>not</u> normally distributed. These results indicate that the width of the interspinous spaces is influenced by the anatomic location as well as the age of the horse. According to these results narrow interspinous spaces cranial to T13 and caudal to T18 are significantly less common, particularly in younger horses.

Articular processes/intervertebral joints, ventral spondylosis and new bone formation in lumbar transverse processes

In the lateral oblique scintigrams of the lumbar spine from T18 to L3 or L4 in nineteen horses (19/33) one horse had unilateral mild IRU in the articular processes/intervertebral joint region (Figure 3). None of the nineteen horses had radiographic signs of osteoarthrosis in the intervertebral joints.

Three horses (3/33) had mild IRU in the ventral part of the vertebral body in the thoracic spine, most likely at T12–13, indicating metabolically active changes, which were attributed to ventral spondylosis. The evaluation of scintigrams was done independently of the radiographic examination, and lateral radiographs of the ventral part of the vertebral bodies was not part of the standard protocol used. Therefore the association between scintigraphy and radiography could not be evaluated.

Mild IRU between transverse processes in the lumbar spine was seen in five horses (5/33).

Coinciding radiographic and scintigraphic changes

The spine from T10–L2 was divided into anatomical areas consisting of one dorsal spinous process and the adjacent interspinous spaces and 134 of the total of 357 anatomical areas had IRU coinciding with at least one narrow interspinous space and sclerosis and/or radiolucencies.

The positive predictive value of presence of moderate of severe IRU that at least one radiographic finding was present was 100%, and the positive predictive value of mild, moderate or severe IRU that at least one radiographic finding was present was 83%. The positive predictive value of at least one radiographic finding present that there was moderate or severe IRU was only 8.1%, and the positive predictive value of all radiographic findings present that there was moderate or severe IRU was 13.5%.

Quantitative analysis

The uptake ratio of the dorsal part of the dorsal spinous processes ranged from 0.31–1.61 (mean 0.72, SD 0.21), and the ventral ratio ranged from 0.33–1.25 (mean 0.69, SD 0.17). The calculated uptake ratios in each dorsal spinous process in this study were significantly correlated to the results of the subjective evaluation ($p<0.05$).

Combination of clinical, kinematic, radiographic and scintigraphic data

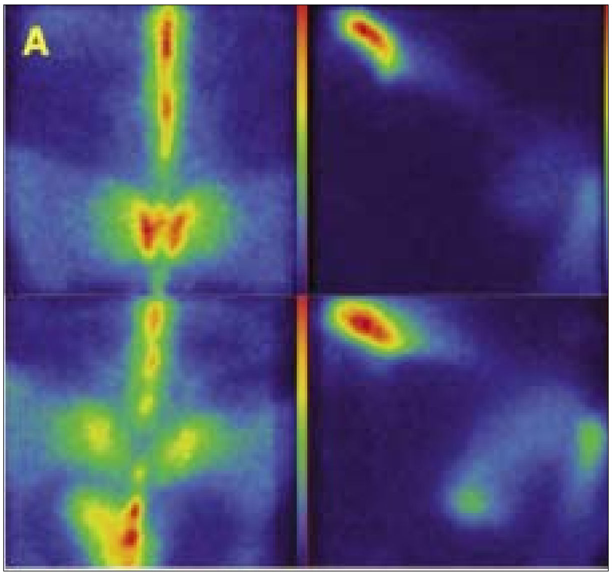
Two horses (6%) were moderately or severely reactive to palpation of the back and 4 other (12%) horses had minor abnormalities when lunged. Three horses (9%) were considered as possible outliers more than twice in the ROM and 10 horses (30%) were considered possible outliers more than twice in the SYM. Coinciding radiographic (more radiolucency, more sclerosis and narrow interspinous space) and scintigraphic findings (moderate or severe IRU) were found in 3 (9%) horses. There were 28 (84%) horses with no or only one change in the clinical, kinematic, radiographic or scintigraphic examinations. The overall results are summarized in table 4 in paper 3. There were no statistically significant associations between the clinical, kinematic, radiographic, and scintigraphic results as classified in this study. The age, gender, use, weight and height of the horses influenced neither, the presence or absence of clinical, kinematic, radiographic, and scintigraphic findings nor the classification of possible outliers in the ROM and SYM.

The sacroiliac joint

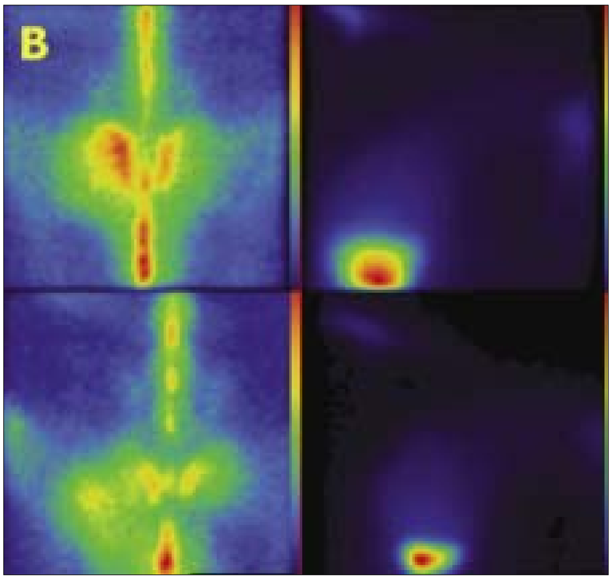
The results of the anatomic study showed that it was possible to locate the SI joint in relation to the tuber sacrale and tuber coxae when they could be identified in the scintigram, and that the sacroiliac joint was located more laterally than previously described. In the subjective evaluation of the SI joints all but one of the asymptomatic horses had normal radiotracer uptake in the SI joints. In the area between the tuber sacrale and the SI joint (the region where previous authors may have diagnosed abnormal uptake as SI joint activity) the scintigraphic appearance varied. The ipsilateral tuber sacrale was used as reference area in the quantitative analysis, and the mean uptake ratio in the SI joint was 0.53 (SD 0.13, range 0.34–0.85).

Important factors affecting the scintigraphic appearance of the SI joint region are: soft tissue attenuation, muscle asymmetry and presence of radioactive urine superimposed on the area of interest. The dramatic effect of soft tissue attenuation was demonstrated by calculating a corrected SI joint ratio. The mean corrected SI joint ratio was 2.14 (SD 0.53, range 1.34–3.60). The possible effect of presence of radioactive urine ventral to the SI joint region was not fully demonstrated through the results because no differences were found between the groups with and without radioactive urine ventral to the SI joint region. Still some examples of how the radioactive urine in the urinary bladder may interfere the evaluation (Figure 17) demonstrate why the possible effect of urinary bladder activity must be considered.

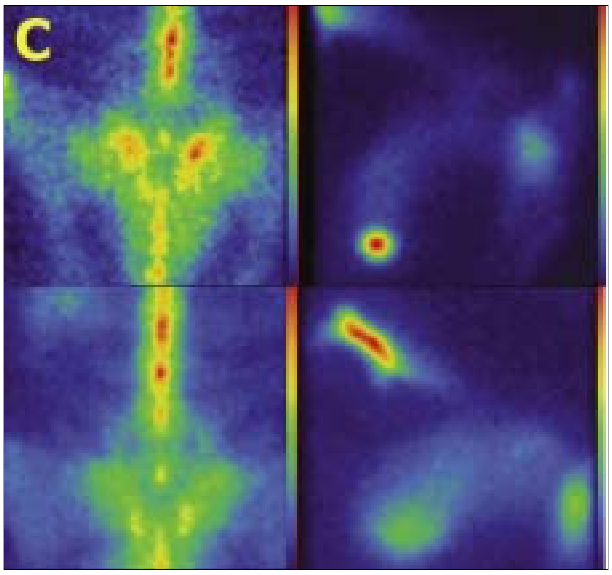
Figure 17: *The scintigrams are a series of two images from six horses: one dorsal view of the pelvis centred over the spine and one lateral view of the urinary bladder with the tuber coxae in the top left corner as landmark. The images illustrate the importance of knowing the location of, and the amount of radioactive urine within the urinary bladder.*



A: *The urinary bladder is empty or located caudal to the SI joint region so there is no risk of misinterpretation.*



B: *The urinary bladder is filled with radioactive urine and is located ventral to the SI joint region. Non-skeletal radioactivity is seen in the dorsal view so the horses were excluded from evaluation because of very high risk of misinterpretation.*



C: *The urinary bladder is filled with radioactive urine and is located ventral to the SI joint region. Non-skeletal radioactivity cannot be identified in the dorsal view thus the horses was evaluated, but with a low risk of misinterpretation.*

General discussion

The material

As one can see from these and previous studies, so called ”normal” horses have numerous ”abnormal” or pathologic changes. Within the context of ”normal” and ”abnormal” findings, one needs to be specific about the definition of ”normal”. The word ”normal” is in the dictionary defined as: agreeing with the regular and established type (104). In the context of diagnostic imaging, the ”normal” appearance may therefore vary with the species, breed, age, gender etc being examined. One risk of defining ”normal” like this is that pathologic conditions that are very common will be classified as ”normal”.

Back pain has been described as a problem mainly in horses used for riding, such as thoroughbreds, partbreds or warm-blooded riding horses. It has even been suggested that the unphysiological ventroflexion of the spine caused by using horses for riding is strengthened by the rider (40). Other breeds may also have back pain, but it may not affect performance in the same way, or have the same clinical implications. To determine the reference range of changes in the spine and pelvis of riding horses, a representative sample of asymptomatic riding horses was chosen to determine which changes are ”normal”. By choosing asymptomatic horses the definition of a ”normal” horse was based on *function*, implying that horses with back dysfunction show signs of pain at palpation of the back or when ridden, lameness, poor performance during competition, or they are unable to perform at all. This definition of ”normal” was done in order to better understand which appearances could be clinically significant in horses with back dysfunction.

Only horses fulfilling specific criteria concerning function and use were invited, and a thorough clinical examination ensured that the horses did not have any other apparent problems, or signs of back dysfunction. Using the distance measurements of the width of the interspinous spaces and uptake ratios of the dorsal and ventral parts of the dorsal spinous processes in 28 horses, both continuous variables, it was possible to estimate the minimum sample size. The confidence interval for the 90th percentile was first estimated with three different statistical methods (Cramér+q90, Bootstrap+q90, Cramér+HD) based on the continuous measurements of these horses (105–107). Then the confidence interval for the 90th percentile was estimated for a sample of 40, 100 and 150 horses, based on the 90th percentile for 28 horses, assuming that the standard deviation is almost constant (107). The width of the 90th percentile confidence intervals for the distance measurements was reduced by between 1 and 2 mm when the sample size was increased from 28 to 100 horses. The 90th percentile would be decreased by 1.5 mm if the sample size were increased from 40 to 100 (Table 3). A similar minor change in the width of the 90th percentile confidence intervals was seen for the uptake ratios. Any additional horse over thirty would minimally improve the result, and the high cost of the whole protocol, limited time, and limited access to horses, which matched the inclusion criteria resulted in the study of 33 horses.

Table 3: *The estimated confidence intervals of the 90th percentile in a sample of 40, 100 and 150 horses, based on the mean width of each interspinous space of 28 horses (107). For this calculation it was assumed that the standard deviation was constant.*

Mean interspinous space width of 28 horses		Confidence interval for the 90 th percentile 28 horses		Confidence interval for the 90 th percentile 40 horses		Confidence interval for the 90 th percentile 100 horses		Confidence interval for the 90 th percentile 150 horses	
T10–11	18.8	16.9	20.7	17.1	20.6	17.7	19.9	17.9	19.7
T11–12	16.6	14.8	18.4	14.9	18.2	15.5	17.6	15.7	17.4
T12–13	15.0	12.5	17.5	12.7	17.3	13.6	16.5	13.8	16.2
T13–14	12.6	10.5	14.7	10.7	14.5	11.4	13.8	11.6	13.6
T14–15	10.5	8.0	13.0	8.2	12.8	9.0	11.9	9.3	11.7
T15–16	10.0	7.9	12.1	8.1	11.9	8.8	11.2	9.0	11.0
T16–17	11.3	9.0	13.6	9.2	13.4	10.0	12.6	10.2	12.4
T17–18	11.5	8.9	14.1	9.1	13.9	10.0	13.0	10.3	12.8
T18–L1	13.7	11.3	16.0	11.6	15.8	12.3	15.0	12.6	14.8
L1–L2	16.8	13.9	19.6	14.2	19.3	15.1	18.4	15.4	18.1

The methods

In a clinical situation it is a great advantage that diagnostic procedures such as radiography and scintigraphy can be done in standing horses. Fewer personnel are required, the examination time can be shortened, the increased risk of general anaesthesia is avoided, and the cost for the owner is kept to a minimum. The protocols used in this thesis were matched to the clinical protocols with regard to timing of injections, choice of views, and acquisition procedures, so that the results would be applicable for the clinical situation. The acquisition of dynamic frames enabled computerized motion correction, to reach a higher total number of counts with less movement artefacts compared to a single static image. The higher counts increased the resolution of the images, and reduced the statistically random errors of quantitative results compared to the shorter average acquisition time allowed by a single static image. Some poor resolution/blurred images of the thoracic spine due to motion could not be avoided, so in horses with substantial intermittent movement a static image with lower counts may have been better. However, it was important for the subjective and quantitative evaluations in this study that the same acquisition time was used for all images, thus none of the frames could be removed even if it would have improved the image quality. It is recommended to monitor the acquired images continuously, so that retakes can be done whenever necessary.

In a recent textbook (45) lateral or slightly oblique views of the thoracolumbar spine were reported to provide most information. Lateral oblique 60° scintigrams from each side of each part of the spine were chosen in this study. For the evaluation of the dorsal spinous processes only two views may not be essential as each process is well visualized from either side. The 60° angle made it possible to get the camera closer to the spine than with the lateral view, although this specific angle was not ideal for all the different shapes of the horses. The importance of a standardized angle should be compared to the advantage of the best possible resolution. Adjusting the angle to the horse is recommended to improve image resolution as much as possible when a standardized examination procedure is not mandatory. In most cases one also wants to evaluate deeper structures of the equine thoracolumbar spine, and then two views are recommended to avoid misinterpretation due to superimposition of other structures such as the kidneys.

Using an ultra fast film and fast screen combination, together with a short film-focus distance enabled visualisation of the articular processes/intervertebral joints in radiographs of the caudal thoracic and lumbar spine. Superimposition of the right and left intervertebral joints and the vertebral body occurs when a lateral view is taken, but the number of possible radiographic projections of the spine to take in a standing horse is limited. One or two lateral radiographs of this area cannot be considered a complete examination because only significant changes in the articular processes are likely to be identified in this view. To make the examination of the articular processes/intervertebral joints as complete as possible a scintigraphic examination with lateral oblique views from both sides is recommended even if the sensitivity for detection of possible degenerative changes in the articular processes has not been determined. Decreased sensitivity because of soft tissue attenuation caused by the lumbar muscle mass must be considered.

Evaluation of scintigraphic images: Subjective evaluation

Interobserver variability, a well known source of variation in radiographic interpretation, most likely occurs in the evaluation of scintigrams. Variation most likely occurs when different observers have different criteria for the same subjective grading. Interobserver variability may be even higher with scintigraphic images, compared to radiographic images, as the sources of variation are greater. These sources are: setup of camera and computer software, acquisition technique, image quality, and evaluation procedures. It would have been interesting to determine interobserver variability in scintigraphic interpretation, but it was regarded to be beyond the scope of this study. In this study it was more important to reduce potential variability by choosing a standardized evaluation procedure, and using a consensus opinion between two observers. The standardized evaluation procedure consisted of: motion correction, rescaling of images acquired by the same time, specific criteria for the grading of IRU, evaluation in two different colour displays, and reading of raw and filtered images.

Evaluation of scintigraphic images: Quantitative analysis

The major advantage of quantitative evaluations is that objectivity can be added to a result in order to compare results, measure healing processes and increase the specificity of certain examinations. In human medicine quantitative bone scanning is considered of limited value in the initial diagnosis of focal bony lesions, because abnormalities are usually easily identified (103).

A major concern in quantitative evaluations is the statistic validity of the result (108, 109). The mean pixel count in the ROIs in the dorsal spinous processes in these studies ranged from 10–62 (mean 28, SD 7), and in the SI joints the mean pixel count ranged from 22–66 (mean 42, SD 8). These numbers are low and indicate poor statistical validity. For comparison Dyson has stated that when the figure is less than 20 in solar views of the foot, the region must be considered cold (30), but otherwise no written guidelines exist to how many mean counts per pixel in the ROI is necessary for adequate statistical validity. Other reasons for low signal/background ratio may be: motion unsharpness, decreased resolution because of the distance between the bone and the collimator when the camera cannot be placed in contact with the horse, the anatomic closeness of the dorsal spinous processes within the horse, so that the background in between may be difficult to distinguish.

Because all examinations in these studies were done in standing horses, it was difficult to increase the number of counts. There is a limit to how long the total examination time of the horse can be before some horses stop cooperating: therefore a standard acquisition time of 90 seconds was chosen. Having the horses under general anaesthesia would have increased the risk, cost and time of the examination, and was therefore not an option. Motion artefacts were reduced by using a motion correction programme, and potential variability due to manually drawn ROIs was reduced by using a semiautomatic programme. A low signal/background ratio resulted in difficulty in subjectively distinguishing between the area of interest and the background, but the semiautomatic programme made it easier to draw consistent ROIs in the dorsal spinous processes, SI joints and reference areas, based on the anatomic landmarks that could be identified. Some background had to be included in the ROIs in the dorsal spinous processes in the thoracic spine as the margin of the process could not be exactly defined by the ROIs, but this potential influence was considered lower compared to the variability caused by manually drawn ROIs. Also the mean pixel count in the ROI used for the calculation of the uptake ratio in each dorsal spinous process was calculated by using the *weighted mean* in the ROI. The weighted mean lets the pixels with more counts within the ROI contribute more to the calculated weighted mean than the pixels with lower counts.

The choice of reference area is essential for a correctly calculated uptake ratio. The tuber sacrale had a much higher mean pixel count than the rib, but both areas showed low variability and were used as reference areas. The rib was used as reference to calculate the uptake ratio in the dorsal spinous processes, and the tuber sacrale to calculate the uptake ratio in the SI joint. Only when the uptake in a selected reference area is stable, both between horses and between different laboratories, uptake ratios can be compared.

Although calculations of the information in the images showed that the statistical validity of the semi quantitative results was low, the association with the subjective evaluation was significant. Hence there is reason to believe that the described semi quantitative procedures may improve the results despite low mean pixel counts. However, in all scintigraphic images with a low total number of counts and/or a low signal/background ratio, semi quantitative assessments must be interpreted with care, and the results are not recommended to be used alone.

Soft tissue: Attenuation

Because the SI joints are covered by the thick gluteus medius muscles the attenuating effect was measured by ultrasound. The mean thickness of the gluteus medius muscles over the SI joint of all horses was 11 cm, causing attenuation of 82% of the gamma rays from the bone. Because the pelvic musculature causes massive attenuation of the gamma rays, it seems reasonable to assume that only lesions in the SI joint with severe bony changes and severe IRU can be detected reliably because of accompanying high amount of scatter and low counts.

The effect of soft tissue attenuation should be considered in all areas of the horse where the amount of soft tissue is more than a few centimetres, but especially when the deeper parts of the skeleton are examined. When e.g. the hip joint of a large horse is examined, the muscle mass dorsal to the joint may be 25 cm thick, causing 98% attenuation. Obviously the IRU in a lesion must be of a certain magnitude in order to be detected because of the above mentioned factors.

Soft tissue: Asymmetry

Because of the significant impact of soft tissue attenuation in equine skeletal scintigraphy, it is essential that the amount of soft tissue overlying the bone is the same when one side is compared to the contralateral side. Obviously the muscle mass of a horse cannot be changed, but since unilateral muscle atrophy will give a false impression of increased uptake compared to the contralateral side, presence of asymmetry must be known to the interpreter. It may be difficult to evaluate muscle thickness by inspection, so it is recommended to measure the muscle thickness with ultrasound. Ultrasound measurements are easy to perform, but the shape of the bone-surface and muscle, the angulation of the probe and how the horse stands are factors, which may affect the muscle measurements. A standardized procedure should be developed for the measurements to decide if asymmetry is present.

Specific imaging problems caused by renal secretion of the radiotracer

The excretion of radioactive urine may interfere with the evaluation of both the thoracic spine and the pelvis. In the left 60° oblique view of the thoracic spine the right kidney is often superimposed on the dorsal spinous processes, and in the evaluation of pelvic images the urinary bladder may be superimposed on the areas of interest. Even if horses are given the diuretic furosemide prior to the examination, there may be radioactive urine left at the time of examination. To include a lateral view of the urinary bladder using tuber coxae as landmark was found essential to determine the location and amount of radioactive urine within the bladder at the time of examination. With help from these views we could either determine if there was no risk of misinterpretation because the urinary bladder was empty or located caudal to the SI joint region, or obvious non-skeletal activity in the dorsal view could be confirmed as originating from the bladder so that horses could be excluded from evaluation. In horses where the bladder was located ventral to the SI joint region without obvious non-skeletal activity in the dorsal view it was impossible to determine if the bladder activity contributed to the activity in the SI joints. Because the uptake ratio between the horses with and without bladder activity ventral to this region was the same, we considered that only in cases which there was extra skeletal activity around the SI joint was the bladder activity contributing significantly to SI joint counts.

In a clinical situation it is recommended to note the amount and location of the radioactive urine within the bladder by including a lateral view of the urinary bladder together with a landmark such as the tuber coxae, because the amount of radioactive urine in the urinary bladder may vary, and the urine sometimes is not equally distributed in the bladder (Figure 17).

The results

Dorsal spinous processes

It seems as if the scintigraphic changes in the dorsal spinous processes of these asymptomatic horses were similar to those described in horses with various clinical signs (15, 17, 19, 20), although the procedures of the subjective evaluations in previous studies have not been described in detail. The intensity of the radiotracer uptake was not graded in these studies and one of the studies used analogue images. It is difficult to know exactly where the limit between ”normal” and ”abnormal” has been set before; therefore it is difficult to make a direct comparison of the results. The overall mean uptake ratios in the dorsal and ventral parts of the dorsal spinous processes found in this thesis ranged from 0.53–0.82. The dorsal uptake ratio in dorsal spinous processes from T13–17 with IRU ranged from 0.60–1.61, and in dorsal spinous processes without IRU the range was 0.37–1.16. Although the calculated uptake ratios have not been presented in detail in one previous study (15), it seems as if they must have been higher. The images in this study were acquired with horses under general anaesthesia, so it is likely that the scintigraphic images had a higher number of counts with less motion artefact (15) explaining the apparent different range of the uptake ratio. The limit in this study (15) for an abnormal uptake ratio in the dorsal spinous processes was set at >1.5, whereas all uptake ratios in this thesis including those of dorsal spinous processes with moderate or severe IRU were lower than 1.61. Using the described limits only one of the horses examined in this thesis (1/33) would have had abnormal ratios in two dorsal spinous processes. According to the criteria used in the subjective evaluation in this thesis there were nine ”normal” horses without IRU (9/33) in the dorsal spinous processes, and the association between IRU and the uptake ratios was highly significant. These differences demonstrate both the importance of each laboratory using its own normal ranges as is the case in human medicine, and the difficulty to set a limit between normal and abnormal radiotracer uptake expressed as a ratio. The semi quantitative results strongly supported the results of the subjective evaluation even if the actual numbers demonstrate an overlap between the ratios in dorsal spinous processes with and without IRU. An uptake ratio for the intervertebral joints was not calculated in this thesis because the number of counts in the ROIs were considered too low.

The radiographic findings in the dorsal spinous processes of these asymptomatic horses were also similar to those described in both normal horses and horses with clinical signs, although the existing grading system was modified for the description of the structural changes in the spine. Previous studies combined all findings in one horse as a single grading score (13, 14) whereas in the present study sclerosis and radiolucencies in each spinous process were recorded, together with measurements of the actual width of the interspinous spaces. The different methods of describing the radiographic findings has made it difficult to compare results in detail. The summation of all scintigraphic and radiographic changes in this thesis was done in three different ways: 1) within a predefined anatomic area, 2) by determining the number of horses without any changes, and 3) by counting the number of affected dorsal spinous processes in each horse. A summation of findings in previous studies (15, 17, 19) has been done without providing the detailed information about the grade and location of findings, and again a comparison of results is very difficult. It may be that differences between asymptomatic horses and horses with clinical signs could be found if the modified grading system within each anatomic location were to be applied on a group of clinical patients. Horses with clinical signs could differ from the asymptomatic horses by having other combinations of coinciding changes, always having changes, or having a higher number of affected dorsal spinous processes. Only when this comparison has been done is it possible to say if any of the combinations are more likely to cause pain.

Articular processes/intervertebral joints, ventral spondylosis and remodelling in lumbar transverse processes

Signs of degenerative changes in the thoracolumbar articular processes has been demonstrated in post mortem studies of boiled specimens of normal horses (38, 39), and in formalin fixated spines from horses with ”kissing spines” (40). In scintigraphic studies of the back of clinical patients, IRU in the intervertebral joints have been described (15, 19, 20) in addition to the calculation of an uptake ratio where the uptake in each intervertebral joint was compared to the uptake in rib 16 (15). Radiographic signs of osteoarthrosis and degenerative changes in the intervertebral joints such as subchondral sclerosis, irregular joint margins, periarticular proliferations of live horses as has been described in one study (15) and in textbooks (45, 110). Histopathologic evidence of osteoarthrosis corresponding with mild changes seen with radiography, and a discussion about radiography being an incomplete examination of the intervertebral joints is lacking.

Osteoarthrosis in the intervertebral joints has been considered important in horses with back pain as an important part of the ”kissing spines” syndrome (19, 20, 40, 45), especially because former radiographic technique did not allow visualisation of these joints other than in anaesthetized horses. The importance has been thought to be so high that horses with evidence of intervertebral osteoarthritic changes in the intervertebral joints have not been recommended to be treated surgically for the ”kissing spines” lesion (20). Currently the clinical significance of degenerative changes in the articular processes of the thoracolumbar spine is debated. The high prevalence of these types of changes found in normal horses (38) questions the clinical significance, in contrast to the opinion in a recent textbook where lesions in the intervertebral articulations are thought to be more consistently associated with back pain than ”kissing spines” (45). We found one horse with mild IRU in two intervertebral joint regions, and no radiographic signs of degenerative changes in the articular processes. However, it is difficult to exclude minor degenerative changes using this examination technique.

The vertebral bodies in the thoracic spine may be radiographically visualized where the lungs are superimposed, but using a different radiographic technique with different exposure values than for the dorsal spinous processes, and a more ventral centring. The prevalence of ventral spondylosis in horses is not known, but based on the scintigraphic findings in this material we believe that the prevalence of active ventral spondylosis in asymptomatic horses is low.

Changes described as new bone formation and pseudoarthrosis in the transverse processes has been reported in normal horses (38, 39). Just as with the changes in the intervertebral joints, the clinical significance of changes in the transverse processes in the lumbar spine is not known. The transverse processes cannot be evaluated radiographically, but with scintigraphy we found five horses with mild IRU that probably were caused by these changes.

Combinations of different examination techniques

The scintigraphic and radiographic examinations of these asymptomatic horses showed that several mild changes are common, suggesting that mild changes should be included in the reference range. However, moderate and severe changes were also present in asymptomatic horses indicating that moderate or severe IRU, more sclerosis, and more radiolucencies not necessarily have to cause pain. The grouping of sclerosis and radiolucency together was done to avoid too many groups of classifications, knowing that the pathogenesis of these changes may not be the same. However, the association between sclerosis and radiolucencies was highly statistically significant. Similar to previous reports (15, 19, 20) it was also found in this thesis that radiographic changes may have scintigraphically IRU, but they may as well not and vice versa.

By combining the changes seen with radiography and scintigraphy, with the results of a clinical and kinematic examination, it was possible to describe a reference range of the combined results. But it was also important to describe the whole range of combinations occurring in the population of asymptomatic riding horses.

The results of the clinical examination were crucial for being included to the study, and horses with pain, lameness or other signs of dysfunction were not included. The registered clinical findings revealed a broad spectrum of findings in the included horses, but the essential criteria was that the horse worked well in the riding test, with no signs of discomfort. Obviously the skills of the rider had a major impact, and one can only speculate on how the horses would have performed with better or worse riders. May be good riders can get horses with minor problems to perform well? Secondly, the potential ability of each horse was difficult to determine based on the clinical examination and riding test. Could the horses with more than mild changes have performed even better if they had not had these changes? At the moment this is also open to speculation, but of less importance as long as the horse's level of performance was satisfactory for the rider.

The kinematic examination was incorporated in the study to get an objective measurement of function, and the technique and protocol has been verified by others (44). Flexion/extension and lateral bending angular movement patterns, including the range of movement (ROM) and symmetry of movement (SYM) for the vertebrae T10, T13, T17, L1, L3 and L5 could be revealed using this approach. It is likely that horses with back dysfunction have different movement patterns compared to normal horses, so to be able to identify horses with back dysfunction, the normal range of each measurement had to be known. To determine the reference range, possible outliers in the ROM and SYM were identified. Horses identified as possible outliers more than twice were used to demonstrate the outer range of kinematic findings.

In conclusion of the combined results, it was possible to fit most horses in to one group, based on clinical, kinematic, radiographic, and scintigraphic data, when the classified results from each examination technique were used. According to these results abnormal changes such as: coinciding moderate or severe IRU, more sclerosis and/or radiolucencies, and narrow interspinous spaces in the dorsal spinous processes, moderate or severe reaction to palpation, minor abnormality when lunged, or being an outlier more than twice in the kinematic analysis did not cause detectable back pain or dysfunction. These abnormalities could either be old changes, or they simply demonstrate how abnormal changes do not have to cause back pain or dysfunction at all. The next step will be to examine horses with back dysfunction and pain. The more the results from these horses differ from what was found in asymptomatic horses the easier it will be to separate the significant changes which can guide the examiner to point out the correct cause of the problem, in order to initiate the appropriate treatment.

The sacroiliac joint

The SI joint has been considered an area of potential clinical relevance in horses with back pain and hind limb lameness since 1975 (10), and Tucker et al. claimed that scintigraphy of the equine SI joints was a sensitive tool to detect lesions in this joint (66). In a recent study 99% of the horses with pain in the SI joint region had abnormalities of the SI joint region identified using nuclear scintigraphy (10), but because of an overlap of results between normal horses and horses with clinical signs (67) it is suggested to use scintigraphy together with a careful clinical examination and local analgesia to reach a more definite diagnosis of SI joint region pain. The same overlap has been demonstrated in numerous studies in human literature, and although scintigraphy of the sacroiliac joints has played an important role in the diagnosis of sacroiliac joint syndrome in man, the examination is rarely done in large hospitals in Sweden and Norway today (84–88). Consequently many hospitals have replaced scintigraphy with other modalities such as CT or MR, but unfortunately these modalities are currently not suitable for the examination of the equine pelvis.

The different conclusions by Tucker et al. and Dyson et al. can be explained by the two very different approaches. Tucker et al. located the SI joint by injecting a radiopharmaceutical into the joint (66), and Dyson et al. used the radiograph of a bone specimen superimposed on the scintigraphic image (67). It is likely that the evaluated areas have not been the same, hence the different results. Because the angle between the pelvis and the camera may affect the apparent location, and the superimposition of the os ilium over the joint produces difficulty in determining the margins of the joint, another approach to determine the anatomic location was chosen in this thesis. The position of the pelvis in a standing horse was simulated, and together with the articular margins of the joint several landmarks were identified. Using the landmarks it became easy to precisely identify the actual SI joint, and the area between the tuber sacrale and the SI joint where previous authors may have diagnosed abnormal uptake as SI-joint activity. In this thesis the scintigraphic appearance of the area between the tuber sacrale and the SI joint (area 2) was evaluated to compare the results of asymptomatic horses with previously described changes in clinical patients. Nineteen horses had mild or more IRU in this area suggesting that the variability of IRU in this area is higher compared to the SI joint. The IRU in area 2 could be due to activity in ligament and muscle insertion sites in the cranial os ilium and the tuber sacrale, or lesions in the bone such as stress fractures and other bony reactions. The apparent IRU in this area could also be caused by difference in shape and size of the tuber sacrale and medial part of the os ilium, or difference in thickness of the muscle, ligaments and other soft tissue structures dorsal to this area. However, the clinical significance of these changes is doubtful considering that the examined horses were asymptomatic. If IRU here should have clinical implications, it should not be confused with abnormality in the SI joint.

One other study has described the scintigraphic appearance in the SI joints in normal horses (31). The area evaluated in this study overlaps two separate areas evaluated in this thesis, and the procedure of describing the scintigraphic appearance is different. Dyson et al. did a subjective descriptive analysis of horizontal profiles superimposed over the SI joint regions and used a quantitative analysis calculating an uptake ratio. The ROIs were drawn manually and the ROI around the SI joints included the tubera sacrale. The uptake ratios were calculated using background subtraction and the fifth lumbar vertebra as reference. In this thesis the radiotracer uptake in the SI joints was evaluated in the scintigram by comparing the uptake in the SI joint with the uptake in a reference area, the ipsilateral tuber sacrale. Also the approach for the quantitative analysis differed, as a dedicated computer program was used to identify the SI joint guided by two landmarks, the tuber sacrale and tuber coxae, and the reference area used was the ipsilateral tuber sacrale. Because of these very different methods it is impossible to compare the results.

Any questions concerning what type of lesions may occur in the equine SI joint, and how these can be diagnosed have not been possible to answer with these studies of asymptomatic horses. Neither if lesions in the SI joint should be considered as a possible cause for back dysfunction. However, the value of scintigraphy to detect lesions in the SI joint in horses is questioned. The gluteus medius muscle attenuates the majority of the gamma rays emitted from the SI joint compromising the sensitivity of the method severely. The specificity of the method for sacroiliac joint injuries in the horse is not known, but it is likely that the specificity is low in horses as in man, as scintigraphy generally is a method with high sensitivity and lower specificity. Consequently scintigraphy of the SI joints in horses with mild hind limb lameness or poor performance may be the best diagnostic test available, but it is still a diagnostic test with low sensitivity and low specificity.

Conclusion

Mild IRU in the dorsal spinous from T13–17 is within the normal range in asymptomatic riding horses, often together with mild sclerosis, radiolucencies and narrow interspinous spaces. Changes within this range should not be interpreted as clinically significant when corresponding clinical signs are absent. In the same area of the back the relationship between coinciding scintigraphic and radiographic changes demonstrated a large variation. Narrow interspinous spaces without radiographic or scintigraphic changes was the most common combination from T15–L2.

A semi quantitative method using a dedicated computer software program, and the weighted mean to calculate the mean pixel counts in the ROIs was important to improve the statistical validity of the uptake ratios. This procedure can be essential to reach the significant association between the results of the subjective evaluation and the uptake ratio.

At least one clinical, kinematic or radiographic and scintigraphic change must be expected in a majority (85%) of asymptomatic horses when the changes are; moderate or severe reaction to palpation, problems maintaining the gait correctly, short hind limb stride or stiffness during lunging, possible outlier in the kinematic data twice, coinciding more sclerosis, more radiolucency and narrow interspinous space, and moderate or severe IRU in the dorsal spinous processes.

Using the tuber sacrale and the tuber coxae as landmarks in the dorsal view of the equine pelvis enables precise identification of the SI joint. In asymptomatic horses it is rare with IRU in the SI joints.

Soft tissue attenuation has a dramatic effect on the scintigraphic appearance of the SI joint region because the gluteus medius muscle over the ilium attenuates 71–82% of the gamma rays from the bone, when the muscle mass is similar to this group of horses. Soft tissue attenuation was found to severely compromise the result and indicated that only lesions in the SI-joint with severely increased radiotracer uptake can be detected with scintigraphy. Knowledge about presence of radioactive urine ventral to the SI-joint region, and assessment of muscle symmetry is essential for a correct subjective evaluation. Any situation with difference in muscle mass between the left and right side of the pelvis will give a false impression of increased radiotracer uptake on the side with lesser muscle mass. In a clinical situation it is also recommended to note the amount and location of the radioactive urine within the bladder by including a lateral view of the urinary bladder together with a landmark such as the tuber coxae. The amount of radioactive urine in the urinary bladder may vary, and the urine sometimes is not equally distributed in the bladder, which may create a false impression of IRU in the SI joint region.

A semi quantitative method with a dedicated computer program was found useful to calculate an uptake ratio with high repeatability. However, for the reasons mentioned above, a ratio corrected for soft tissue attenuation should be used. To determine if this procedure is clinically useful in horses with back dysfunction and/or hind limb lameness, the uptake ratio in these asymptomatic horses must be compared to horses with clinical signs.

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