Single-Photon Emission Computed Tomography of the pelvis and lumbar spine contributes to the diagnosis of injury in two horses.

Keywords: horse, lameness, musculoskeletal, sacroiliac, nuclear scintigraphy

Summary

This article describes the clinical use of Single Photon Emission Computed Tomography (SPECT) in two horses to aid the diagnosis of injury to the region of the sacroiliac joint and lumbar vertebrae which was not identified on planar imaging.

Introduction
Nuclear scintigraphy is a highly sensitive and non-invasive diagnostic modality that aids examination of the musculoskeletal system of the horse. The use of nuclear scintigraphy is not only indicated in cases where lameness has been localised to a non-specific region of the musculoskeletal system, but also in the general screening of horses with vague signs of poor performance (Dyson, Musculoskeletal Scintigraphy of the Equine Athlete, 2014). The major advantage of nuclear scintigraphy when compared to other diagnostic imaging modalities is that it provides diagnostic information on the physiologic function of a tissue (Spelberg & Ross, 2012). Scintigraphic planar imaging, however, has the drawback of portraying the three dimensional distribution of radioactivity in a two dimensional image with no depth information and superimposition of overlying structures, thereby reducing image contrast in the plane of interest (Gemmell & Staff, 2005).

The use of computed tomography (CT) and magnetic resonance imaging (MRI) in equine lameness investigation is becoming more common worldwide, overcoming the poor anatomic detail inherent to planar scintigraphy. These imaging modalities however only provide information on structural alterations and are less suitable for occult functional pathology. CT and MRI imaging is also limited to the distal limbs, cervical spine and head due to the large size of the horse.

In human medicine single-photon emission computed tomography (SPECT) is undertaken to improve image contrast and separate overlapping structures, thereby improving visual interpretation images (Groch & Erwin, 2000). SPECT takes conventional two-dimensional nuclear medicine images acquired on different planes around the patient, and with the aid of
computer modelling, provides an estimate of the three-dimensional radioactivity distribution using methods of image reconstruction from multiple projections (National Research Council, 1996).

The use of SPECT in veterinary medicine has been reported in small animal oncology (LeBlanc and Peremans, 2014), canine behavioural disorders for cerebral blood flow studies (Or, et al., 2017) and the evaluation of canine orthopaedic diseases (Peremans K, 2013). To date, the use of SPECT imaging in the horse has been limited by a lack of suitable equipment to accommodate the horse due to size limitations, and a need for specific processing software capable of accommodating motion correction (LeBlanc & Peremans, 2014). This report describes the use of SPECT imaging of the equine pelvis in the standing horse and the identification of lesions which were not observed using traditional two-dimensional nuclear medicine imaging.

Case details: history and clinical findings

Case 1

A 5-year-old, 508 kg, pacing Standardbred gelding was referred to Ascot Equine Veterinarians for full body scintigraphy, to aid localisation of the source of a reported lameness which was only apparent at high speed. The gelding was examined on multiple occasions by the referring veterinarian with the complaint of breaking into canter during fast pace work. On each occasion when examined by the referring veterinarian, no overt lameness was detected. The trainer of the gelding reported that, when medicated with phenylbutazone, the horse did not break stride during fast pace work.
The gelding was in full race training when presented for examination. On clinical evaluation, there was subtle atrophy of the left middle gluteal muscle compared to the right. No other abnormalities were detected on palpation of the musculoskeletal system. On gait evaluation at the walk and trot on a hard surface in a straight line, no overt baseline lameness was detected. Flexion testing of all four limbs was unremarkable. Pelvic width measured at the level of the tuber coxae was 63 cm.

Case 2

A 4-year-old, 550 kg, Thoroughbred flat racing gelding was presented for half body scintigraphy (hind end only), to aid in localisation of the source of bilateral hind limb lameness. This gelding returned to race training four weeks prior to presentation, following an 8 week period of paddock rest due to reported sudden onset of poor racing performance. Despite the rest period from race training, the gelding continued to demonstrate a bilateral hind limb lameness at the walk, which improved as the horse warmed up. The level of lameness was reported to increase when cantering was commenced.

Physical examination of the gelding revealed a loss of gluteal muscle mass, which was more marked on the left side when compared to the right and marked lumbar back pain on palpation. No overt joint effusions were detected on palpation in either hind limb. The gelding displayed marked initial bilateral hind limb lameness at the walk, characterised by marked reduction in stride length and marked reduction in limb protraction in both hind limbs. During gait evaluation, the level of lameness improved dramatically, to the point that no lameness was evident at the walk. On the straight line trot out, the gelding displayed bilateral shortened stride length in both hind limbs, with a consistent grade 2/5 (American Association of Equine
Practitioners 2020) left hind limb lameness. A moderate pain response and exaggerated lameness was observed following full limb flexion testing in both hind limbs. On evaluation at the trot on a circle, the gelding displayed a grade 2/5 lameness in the left hind limb on the left rein, and grade 2/5 lameness in the right hind limb on the right rein. Pelvic width measured at the level of the tuber coxae was 65.5 cm.

**Scanning protocol**

The evening prior to scintigraphy, both horses were admitted to the hospital, rugged overnight and wool lined boots were applied to the distal limbs. On the day of scintigraphy, a jugular catheter was placed and 5 GBq, consistent with previous reports of 1Gbq/100kg body weight (Dyson, Murray, Branch, & Whitton, 2003) of $^{99m}$Tc-hydroxy methylene diphosphonate was administered intravenously. Two hours following administration of the radioisotope, the horses were sedated with 5 mg of butorphanol tartrate and 5 mg of detomidine hydrochloride intravenously via the catheter, and bone phase imaging was commenced. The horses received further bolus doses of 3 mg detomidine hydrochloride intermittently as required to complete acquisition of imaging.

A GE Healthcare Millennium MPR Gamma Scanner on a ring gantry interfaced to a GenieAcq system was used to acquire routine two-dimensional images of the entire horse in Case 1. Imaging included the head and neck area, dorsal and lateral thoracic spine and a conventional overview of the fore legs (lateral shoulders, lateral and dorsal elbows, lateral and dorsal carpi and lower limb) and hind legs (lateral pelvis and coxo-femoral joints, lateral and caudal stifles, lateral and plantar tarsi, lateral and plantar hind fetlocks). In Case 2, two-dimensional images of the hind limbs, pelvis and spine rostrally to the thoracolumbar junction were undertaken.
Planar images specifically of the pelvis and lumbar vertebrae included the dorsal, dorsolateral oblique on each side along with the caudal (pelvis) and lateral views. The scanner underwent standard quality control intrinsic floods and resolution phantom performance tests to confirm 99mTc isotope peak, uniformity and resolution criteria met acceptable limits prior to imaging. The series was acquired as 2 second per frame dynamics with a 128x128 matrix for a maximum of 90 secs for the appendicular skeleton and 60 seconds for the axial. The average count per pixel for the lumbar-sacral series was 24.8. The raw data was transferred to a GE Healthcare Xeleris V3.1 Processing system in Digital Imaging and Communications in Medicine (DICOM®) Standard format for both automatic and manual motion correction by a nuclear medicine scientist (PT). A composite was generated from the corrected data for final interpretation.

Upon completion of acquiring traditional planar images for the study, a SPECT study of the pelvic region was performed. The gamma camera was placed in the home position and the camera was raised to allow backing of the horse beneath. Care was taken to ensure that the horse’s midline was centred under the middle of the camera, and the horse was standing squarely. The camera was then rotated 90 degrees to the anticlockwise into the starting position for the SPECT. The detector rotated 180° in a circular orbit stepwise motion for 48 frames (every 3.75 degrees) at 12 seconds per image with high-resolution low energy, parallel hole collimation and 128x128 matrix. SPECT data underwent motion correction and were reconstructed (ordered-subset expectation maximization (OSEM) based iterative reconstruction: 16 iterations, 8 subsets). Transversal, dorsal and sagittal planes were thus generated rendering a 3D volume image. Post-processing filtering consisted of a butterworth filter, cut-off frequency 0.4 rad/s, order 10. Motion detection and correction was first automatically applied (GE Healthcare Xeleris V3.1, VolumetrixMI-MDC) followed by manual
adjustment of X and Y motion to optimise the corrected linogram and sinogram parameters for
reconstruction.

Imaging findings:

Case 1

Static images

Examination of the planar images of head, neck and fore- and hindlimbs did not reveal
significant focal tracer uptake, except for both lateral sesamoid bones on the caudal view of the
posterior fetlocks. On the planar images of the pelvic area, the tuber sacrale and sacroiliac
region showed asymmetric uptake, with the left region more active, as well as slight
asymmetric uptake at the level of the left iliac wing, axial to the tuber coxae (Fig 1) in the
region of the insertion of the ventral sacroiliac ligaments. Quantitative analysis was on the
dorsal pelvis projection by applying semi-automatic ROI’s over the tuber sacrale (TS), the
sacro-iliac joints (SIJ), and a lumbar vertebrae to provide differential uptake ratios (Erichen,
Berger, & Eksell, 2002). The mean left TS and left SIJ uptake values were calculated as 23.5%
and 10.3% greater than the right side respectively ROI analysis confirmed increased uptake in
the tuber sacrale/sacroiliac area. Due to superposition, more information regarding anatomical
localization of the increased uptake in the TS/SIJ area could not be gained.

SPECT images

On the SPECT images, localized increased uptake was noted in the region of the left SIJ (Fig
2). Images of the same area in a control horse are added for comparison (Fig 3).
Planar images revealed increased radiopharmaceutical uptake (IRU) that was mild and focal in the left distal patella, and mild and general in the left tarsus. No notable increased uptake was present in the remainder of the images, including those of the lumbar vertebrae (Fig 4).

SPECT images

Moderate focal IRU was seen on the transversal, dorsal and sagittal reconstructed images of the lumbar spine at the level of L5: dorsal, in the region of the articular processes/vertebral arch (Fig 5) and more ventral, in the area of the vertebral body (Fig 6), both uptakes more apparent at the left side. There was very mild focal IRU associated with the spinous process summit of L6. Comparable uptake was noted at the level of L3. However, since this occurred at the edge of the image, interpretation was confounded and therefore not reliable. No asymmetric uptake could be seen in the sacroiliac region.

Outcome

Case 1

Case 1 underwent infiltration of both sacroiliac joints under ultrasound guidance, with 10 mg of triamcinolone, by the referring veterinarian. The gelding continued in race training and was reported to break into a canter less frequently at high speed during pace work. The gelding’s suspected lameness at high speed did not fully resolve and as a result the gelding did not successfully return to racing.

Case 2
Case 2 underwent rectal ultrasound examination of the ventral lumbar and sacral spine. Ultrasound revealed periosteal new bone formation on the caudal ventral surface of L5, consistent with periosteal callous formation. No abnormalities were detected in the intervertebral discs of L3-L4, L4-L5 and L5-L6 joints. Spurring of the margin of the L5-L6 joint space on the left side only, consistent with remodelling, was evident. A diagnosis of stress fracture of the fifth lumbar vertebral body was made and a period of rest and rehabilitation of 6 months was recommended.

Discussion

The two cases described demonstrate the use of SPECT imaging in the standing sedated horse to improve diagnostic accuracy of nuclear medicine in detecting pelvic and lumbar pathology. SPECT images in Case 1 demonstrated IRU in the left sacroiliac joint, which was not evident on traditional planar images. In Case 2, when compared to planar images, SPECT imaging demonstrated moderate IRU more specifically at L5. SPECT imaging also helped to rule out involvement of the tuber sacrale/iliosacral region in this case.

Recent publications have questioned the use of scintigraphy as a screening tool for sport horses with poor performance due to low specificity and relevance of traditional planar imaging, especially in the region of the sacroiliac joint (Quiney, Ireland, & Dyson, 2018). This finding is in agreement with earlier human studies, in which traditional planar nuclear medicine imaging was found to have an overall low sensitivity and specificity for detecting sacroiliitis in human cases (Song IH, 2008). SPECT imaging has increased the detection of sacroiliitis in human studies, with a sensitivity of 85% and specificity of 90% (Hanly, Barnes, Mitchell, Macmillan, & Doherty, 1993). More recently, when SPECT and MRI were compared in a...
population of 43 humans with suspected sacroiliitis, SPECT was shown to have complete
terance with the MRI findings, with authors concluding SPECT is a reliable imaging method
in the diagnosis of active sacroiliitis and enthesitis in human patients (Pipikos, Kassimos,
Angelidis, & Koutsikos, 2017). Our SPECT findings in both cases, demonstrate the increased
specificity of SPECT compared to traditional planar imaging.

Although traditional planar images demonstrated increased IRU in the left tuber sacrale and
sacroiliac region in Case 1, SPECT imaging more reliably demonstrated involvement of the
region of the left sacroiliac joint in this case. This finding of increased uptake in the region of
the left sacroiliac joint supports both the clinical examination findings and the history of
reduced performance at high speed reported in this case.

The identification of lesions which result in poor performance or are perceived to only incite
pain during certain gaits or speeds, continues to be a diagnostic challenge for the equine
practitioner. Sacroiliac joint disease has been associated with poor hindlimb action, lameness
and poor performance in horses (Jeffcott, Dalin, Ekman, & Olsson, 1985). A large scale review
of horses with sacroiliac pain reported abnormal RU in only 43% of horses which responded
positively to sacroiliac nerve block (Barstow & Dyson, 2015). Although, in Case 1, the gelding
was reported to have improved following medication of the sacroiliac joints with corticosteroid,
the suspected lameness at high speed did not resolve. In agreement with a recent report on 84
horses with clinical disease localised to the sacroiliac joint (Nagy, Quiney, & Dyson, 2019),
horses with disease of the sacroiliac joints have a guarded prognosis for return to previous
levels of performance. The presence of moderate increased uptake in the iliac wing of Case 1,
axial to the tuber coxae, may also indicate involvement of the ventral sacroiliac ligaments.
Further imaging of the sacroiliac joints and associated ligaments via rectal ultrasound examination may have provided further information regarding the extent and stage of disease in the sacroiliac joints in this case. Unfortunately, this was not pursued by the referring veterinarian.

Pathology of the lumbar vertebrae in the horse is a challenging diagnosis to make premortem (Collar, et al., 2015). Imaging of the region is limited due to overlying anatomy and large muscle mass. The findings in Case 2 are consistent in location with a previous report on fracture of the lumbar vertebrae in racing thoroughbreds (Collar, et al., 2015). In Case 2, mild and focal IRU was observed in the left distal patella, along with mild, general IRU in the left tarsus; with no appreciable IRU in the lumbar spine or pelvis. On the SPECT images however, moderate focal IRU was localised to the vertebral body of L5. Rectal ultrasound examination revealed changes consistent with periosteal callous formation on the normally smooth ventral periosteal surface of L5 (Vautravers, Coudry, & Denoix, 2020), which supported our SPECT findings of pathology in this area.

Post mortem evidence of stress fracture in the thoracic and lumbosacral regions of thoroughbred race horses which suffered fatality on Californian racecourses has been reported to occur in 61% of cases examined (Haussler & Stover, 1998). Given the potential catastrophic complications of ongoing race training in a horse with such changes, the findings on the SPECT imaging in Case 2 was considered to be both career and life saving.

SPECT imaging of the pelvis and lumbar region in the standing horse was feasible in the two described cases by having the camera move in a 180 degree arc over the horse’s hind end.
According to the theory of computed tomography, projection views acquired over only 180° of arc are required for correct reconstruction as projections opposite each other are essentially mirror images of each other (Groch & Erwin, 2000). We acknowledge that the gamma camera is not a perfect imaging system, and due to difference in distance between the patient and camera, along with scintigraphic artefact, opposing views are not mirror images. Despite this, acquiring the SPECT images through a 180 degree arc as described in these cases does markedly improve image contrast allowing improved recognition of pathology present compared to planar films. Superior motion correction software and the configuration of the gamma camera on the ring gantry has enabled the development of the described technique for acquisition of SPECT images in the standing sedate horse.

Despite the successful use of SPECT described in this report, there are some limitations to its use in the standing horse. The size of the gantry opening limits the regions for which potential SPECT imaging of the horse can be undertaken. Image acquisition is also limited to the size of the horses’ pelvis. Pelvic size must be less than the diameter of the arc of flight of the gamma camera. A maximum pelvic width of 67 cm, measured between the point of tuber coxae, was found using the described technique.

Despite the use of advanced motion correction software, lack of patient compliance with movement during acquisition, has a significant influence on image quality. Manual adjustment of the X and Y axis, post automatic motion correction, optimises the corrected linogram and sinogram parameters for 3-D reconstruction. Manual adjustment of the Z-axis, however, is not yet possible using the current motion correction software. It is thus essential that the patient remains as still as possible throughout SPECT image acquisition. In the current case report, a
steady state of sedation, based on individual clinician preference was achieved using a bolus of intravenous detomidine and butorphanol.

To the authors’ knowledge, this is the first report of undertaking SPECT in the standing sedated horse to aid in diagnosis of pelvic pathology. The imaging technique described holds merit in improving spatial resolution and anatomic detail of the equine pelvis, thus increasing confidence in the diagnosis of sacroiliac and lumbar disease. Further research to refine and validate the described technique and fully determine the sensitivity and specificity of detecting true pathology is warranted.

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References


Quiney, L.E., Ireland, J.L. and Dyson, S.J. (2018). Evaluation of the diagnostic accuracy of


Fig 1: Case 1. Dorsal static image of the pelvic area. Note the increased uptake over a larger area in the left sacro-iliac area (thick arrow). Asymmetric uptake is also noted in the iliac wing, axial to the tuber coxae (thin arrow).
Fig 2: Case 1. SPECT images. Focal uptake in the region of the left sacro-iliac joint (cross cursors) on the slices in the 3 dimensions. Top row: transversal slices; middle row: dorsal slices; bottom row: sagittal slices (V: ventral, D: dorsal, L: left, R: right).
Fig 3: **Case 1.** Images on left: three dimensional slices of the sacro-iliac region of Case 1 (transversal (top image), dorsal (middle image) and sagittal (bottom image) slices). Cross cursor placed in the region of the sacro-iliac joint. Images on right: comparable slices of the sacro-iliac region of a control horse. Cross cursor placed in the region of the sacro-iliac joint.
Fig 4: *Case 2.* Static images of the caudal lumbar vertebral area. Top row: dorsal and lateral views. Bottom row: left and right oblique views.
Fig 5: Case 2. Focal increased uptake in the area of the vertebral arch/articular processes (more to the left side) of L5 (cross cursors) seen on the transversal, dorsal and sagittal slices. Further differentiation is not possible due to spatial resolution limits. Top row: transversal slices; middle row: dorsal slices; bottom row: sagittal slices. (V: ventral, D: dorsal, L: left, R: right.)
Fig 6: Case 2. Focal increased uptake in the vertebral body area (mid-left and dorsal region) of L5 (cross cursors) seen on the transversal, dorsal and sagittal slices. Top row: transversal slices; middle row: dorsal slices; bottom row: sagittal slices (V: ventral, D: dorsal, L: left, R: right)