Equine Bone Scintigraphy: What is it and what can it do for me?

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Introduction:

Nuclear Scintigraphy is a highly sensitive, alternative imaging modality used in human and veterinary medicine. This modality involves the administration of a radioactive substance (*radioisotope)* to a patient. Generally, the radioisotope is labeled to a specific compound. This labeled combination is known as a *radiopharmaceutical*. These radiopharmaceuticals are formulated in various chemical forms that will allow them to localize in specific organs (e.g., bone, kidneys, liver). The most common radioisotope label is technetium-99m (^{99m}Tc). Other radioisotopes used include iodine-123, iodine-131, indium-111, thallium-201, and gallium-67. Each radioisotope has different imaging characteristics. The radioisotope and the radiopharmaceutical used depend upon the study performed and the target organ.

Once the radiopharmaceutical has been administered, it will be distributed throughout the body in accordance with its chemical and/or physical properties. The patient will now be emitting radiation in the form of gamma rays (γ-rays), which escape from the body and permit external detection and measurement. γ-rays are electromagnetic radiation similar to x-rays. A special camera, called a *gamma* (or scintillation) *camera*, is used to detect the distribution of the radioactivity within the patient's body. Hence, unlike radiology where the equipment is the radiation source, the gamma camera is only a radiation detector and it is the patient that is the radiation source. The radioactivity distribution in the organ(s) of interest permits an evaluation of both the functional and morphologic status of these organs.

The gamma camera is made up of a special scintillation crystal, which absorbs the γ-rays. The crystal emits the absorbed energy as a flash of light or a series of flashes of light, which is(are) proportional in brightness to the energy absorbed. Many photomultiplier tubes, coupled to the crystal, convert the light to electronic pulses. Electronic circuitry assigns spatial coordinates and amplitude to the signals. In most systems this signal then is converted to digital form and is stored in a suitable matrix on a computer. The computer then reconstructs the image, which can be printed on paper, exposed on film, saved on the hard drive or sent digitally to a Picture Archiving and Communications System (PACS). The imaging computer then may also be used to make easy and non-invasive physiologic measurements for quantitative studies, as well as manipulate images using algorithmic functions for smoothing or sharpening edges, correcting for motion, and windowing to improve visualization of abnormal regions.

Nuclear medicine differs from radiology in the fact that the nuclear medicine images represent physiology, versus the morphologic representation in radiology. Because physiologic changes precede morphologic changes in tissues, nuclear medicine will often detect disease before there are structural changes noted. Nuclear medicine is known for its high sensitivity of detecting disease; unfortunately, nuclear medicine often has a lower specificity than radiographs.

Radiation Safety:
All patients that undergo a nuclear medicine procedure must be kept isolated from the general public while they are emitting radioactivity. This is a designated area that can contain and/or facilitate disposal of contaminated material. Clients are not allowed to visit during the period of confinement.

^{99m}Tc has a half-life of 6 hours. In general, a radioisotope needs 10 half-lives in order to decay to background levels. However, at the same time as the ^{99m}Tc is decaying within the body, it is eliminated through the urinary tract (biological half-life) for most procedures, and therefore the effective half-life of the radioisotope in the patient is shorter than the physical half-life. At our institution, the patients can be released to the general public (the owners) when the radiation they emit is <2.0 mR/hr at surface. Generally, this takes approximately 24 hours.

During the isolation time, radiation safety measures such as wearing gloves, labcoats, booties, and radiation badges are followed by personnel working with the patients. Waste is kept in special containers for decay. Patients will continue to emit a small amount of radioactivity from their body as well as in their urine after being discharged, and the clients are instructed to wash hands after handling the patient or the urine for the next 48 hours.

Bone Scintigraphy:
Bone scintigraphy is the most commonly performed nuclear medicine scan in horses and is indicated in a variety of skeletal disorders because of its high sensitivity and the ease at which the entire skeleton can be imaged. Nuclear scintigraphy represents images of **physiology**. This contrasts with radiography, which represents images of **morphology**. Nuclear scintigraphy can detect diseases that alter physiology before there are morphologic changes in structure. Since there is often a lag period of 7-14 days before there are morphologic changes in bone density, a bone scan can detect bony abnormalities earlier, thus providing better case management. Although nuclear medicine is **more sensitive** than other imaging modalities, it is often **less specific**. Specificity of bone scintigraphy has advanced with improvements in image quality and increasing experience in clinical interpretation. However, it is still recommended that scintigraphy be combined with conventional radiographs or other imaging modality such as CT or MRI to determine the cause of the bony lesion.

The technique of bone imaging begins by labeling a compound (diphosphonate) with the radioisotope, technetium (^{99m}Tc). The resulting pharmaceutical is ^{99m}Tc-MDP(methylene diphosphonate) or ^{99m}Tc-HDP (disodium oxidronate). The radiopharmaceutical is injected intravenously and, after equilibrium with the extravascular space, is thought to absorb via chemical bonding to the hydroxyapatite crystal (inorganic component) in bone. Regions with large surface areas (such as the metaphysis of long bones) allow enhanced absorption. Bone scintigraphy measures the degree of **osteoblastic activity**; however, blood flow to the bone will also affect bone uptake. In the normal state, there is equilibrium between osteoclastic and osteoblastic activity. In many disease states, the bone will respond by changing the balance between the two. Radiographs show the *net effect* of the osteoblastic and osteoclastic activity. Therefore, even lesions that appear lytic on radiographs will often have increased uptake on the bone scan because both the rate of reabsorption and the rate of bone production have increased. These lesions appear lytic on radiographs because the rate of reabsorption is occurring at a faster rate than production. Most bony lesions result in increased osteoblastic activity, therefore bone scintigraphy is very sensitive to detecting bone lesions.

The radiopharmaceutical that is used for bone imaging is eliminated primarily via renal excretion. In the horse, a small quantity is secreted from the sweat glands. The half-life of technetium is 6 hours. Ongoing radioactive decay is also responsible for a decrease in radioactivity of the patient. Until the radioactivity has been excreted and decayed to an acceptable level, the patient must be kept isolated from the general public.

Advantages over radiography:
- High sensitivity for detecting early disease
- Ease of surveying the <u>entire</u> skeleton
- A negative scan virtually rules out active bone pathology and many forms of joint disease (except osteochondrosis)
- Ability to follow-up lesions for resolution
- Software processing such as motion correction and ability for quantification studies

Disadvantages of scintigraphy:
- Patient will be radioactive and must be isolated from the general public
  - At U of MN, the patient can be released after 24-36 hours
- Equipment is relatively expensive
- Generally only offered at larger referral/specialty centers (need special license)

Indications for bone scintigraphy:
- Diagnosis of occult or intermittent lameness
- Bone survey for multiple limb lameness
- Early detection of skeletal injury - fracture
- Determining extent and severity of skeletal lesion – activity of radiographic lesions
- Localization of pain but inability to identify cause using radiography and ultrasonography

- Poor performance of ill-defined cause
- Suspected thoracolumbar or pelvic region pain
- Evaluation of healing response
- Evaluation of blood flow to bone

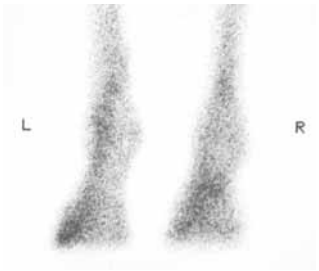
Limitations of bone scintigraphy:
- Not specific (fracture vs. infection vs. tumor) – however pattern recognition is becoming more important in interpretation
- Generally poor for morphology
- Normal stress-induced remodeling in certain use horses can be confusing (young horses in certain types of training)
- Osteochondrosis lesion most often do not produce a detectable change in the scan
- Not necessarily sensitive for osteoarthrosis
- Clinically insignificant lesions will "light up"
- Regional anesthesia will cause increased uptake on the soft tissue phase
- Scintigraphy should not be a substitute for comprehensive exam

There are three phases that can be studied with bone scintigraphy: the vascular phase (dynamic study), the pool (soft tissue) phase (static images), and the bone phase (static images). All three phases can be performed with a single injection of 99mTc-MDP or 99mTc-HDP. The vascular phase is performed to evaluate for blood flow to an area. Inflammation will result in increase flow; whereas, if the bone is non-viable there will be a decrease or void of blood flow. The pool (soft tissue) phase will have increased activity in diseases of inflammation, infection, or those that increase the extravascular space (edema). Increased soft tissue activity in combination with abnormal bone uptake may signify osteomyelitis or acute trauma. The bone phase is performed to evaluate for bony lesion. Fractures, osteomyelitis, and fracture will cause the most intense uptake.

Vascular phase imaging (performed immediately upon IV injection of agent)
- Dynamic acquisition
- Used to evaluate blood flow to an area
  - Inflammation leads to increased flow
  - Non-viable bone shows void of blood flow
- Only one area can be imaged

Pool (soft tissue) phase imaging (performed 3-5 minutes after IV injection of agent)

- Static acquisition
- Determines presence of radiopharmaceutical in extracellular space and vascular pool – passive
- Not particularly sensitive to soft tissue injury
- Nerve blocks and joint injections can cause uptake – usually multiple
- Most useful for lower limb studies and can only image one or two areas



Bone phase imaging (performed beginning 1.5-2 hours after IV injection of agent)

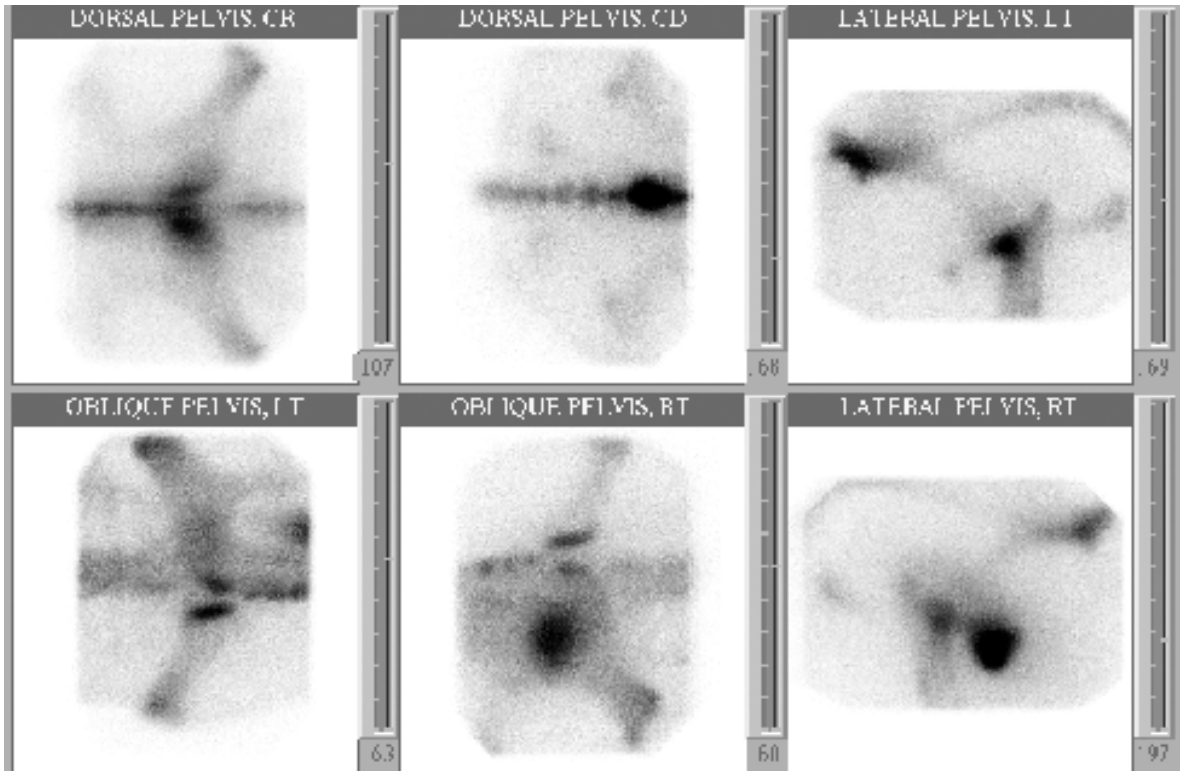
- Detect and evaluate acute or chronic bone disease that involves an increased rate of bone turnover:
  - Acute non-displaced fractures
  - Osteoarthritis
  - Periosteal reaction
  - Enthesopathy
  - Neoplasia
- Detecting dead bone tissue
  - Sequestrum formation
  - Previous trauma

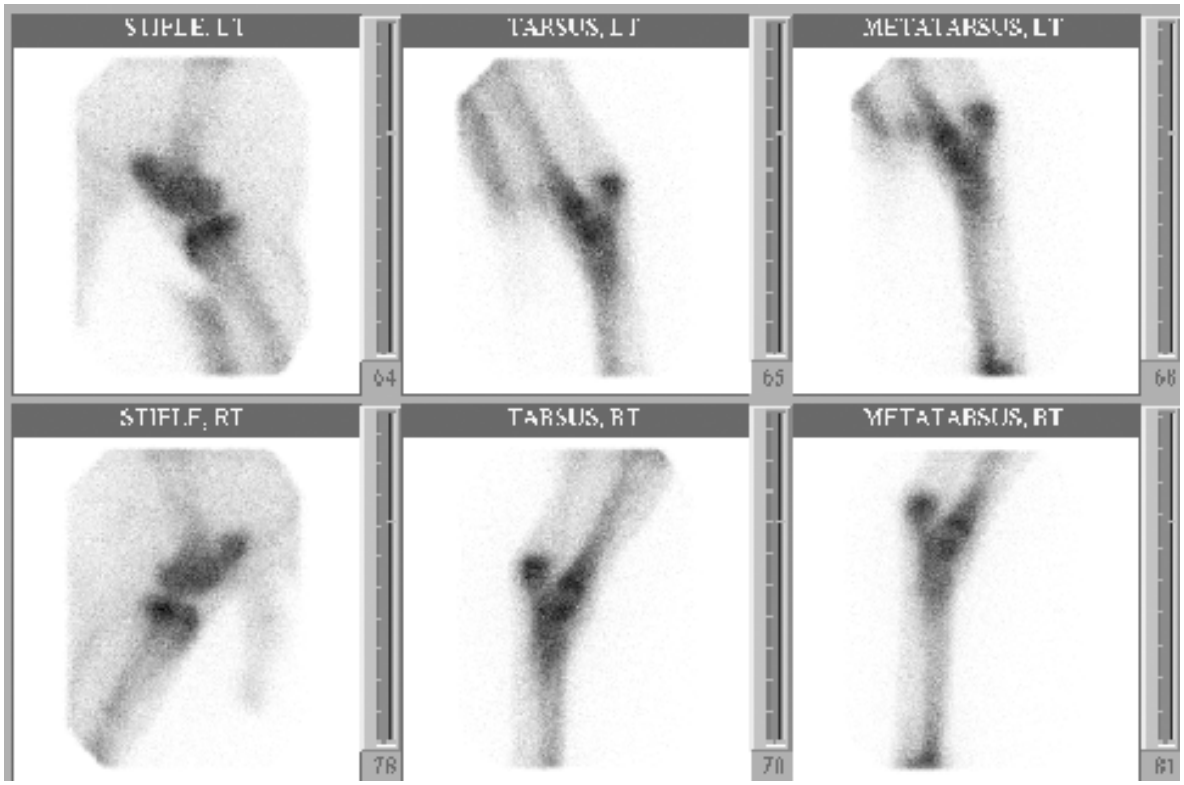
Interpretation:
On a bone scan, the abnormal areas generally show up as a region of increased activity ("hot spot"). The exception to this would be if the piece of bone were dead. This would show up as a region of no activity ("cold spot").

Normal:

- There should be some uptake in all bones that are alive and adequately perfused
- Pattern shows low but consistent uptake in areas of cortical bone and relatively higher uptake in the more actively remodeling trabecular bone supporting the joint surfaces – epiphyseal region of long bones has greater uptake than metaphyseal and diaphyseal regions
- Younger animals have physeal uptake, immature athletes have more intense subchondral bone
- There is considerable variation in uptake even in horses of the same age – generally non-significant uptake tend to be bilaterally symmetric
- Certain types of "normal" uptake are recognized in horses used for various activities. This is known as adaptive remodeling. An example would be linear uptake in the dorsal cortex of the bilateral front P1 in sport horses.

Normal bone phase images of the pelvis, stifle and tarsus of the horse:

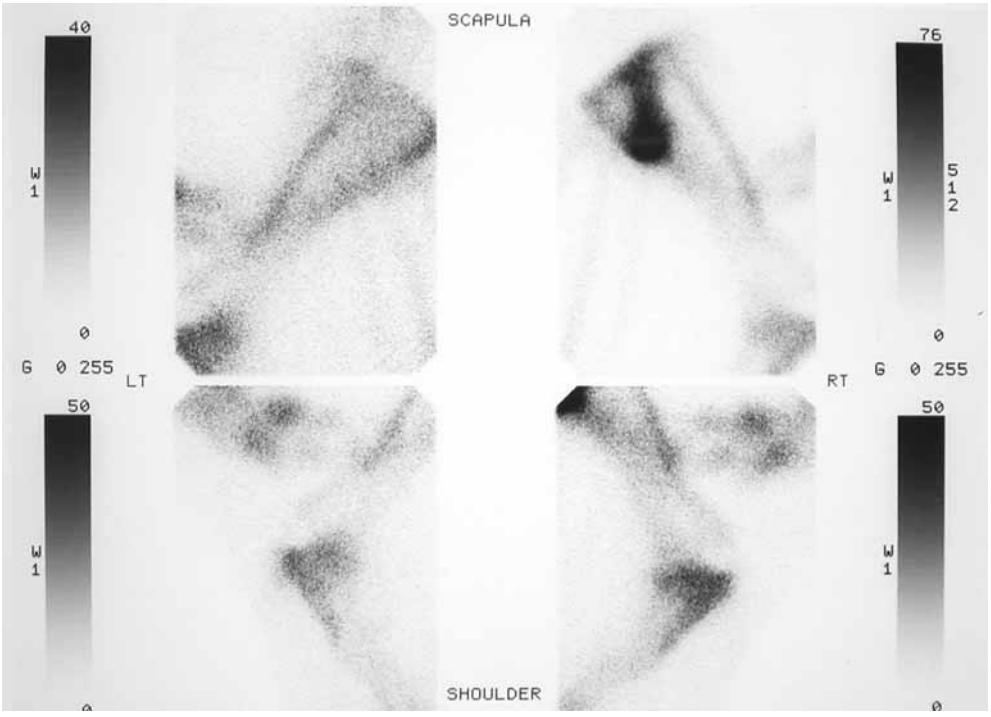




Abnormal:

- Abnormal areas are generally increased in activity ("hot spot")
- Diagnosis is based upon anatomic location and pattern of uptake
  - Assess if area of increased or decreased uptake
  - Identify if uptake is cortical, subchondral or medullary
  - Categorize the intensity of uptake – mild, moderate, marked
  - Categorize the location of uptake – focal, diffuse, linear
- The greatest activity will be associated with fractures, infection and tumor
- DJD has moderate activity on the bone scan, depending upon its activity
- Compare the contralateral sites – however, pathological changes may be bilaterally symmetric
- Important to recognize that increased uptake is not necessarily associated with pathological bone remodeling – and does not always equate with the cause of the lameness
- Certain types of uptake are recognized with horses used for various activities

Bone phase images of a horse with right front limb lameness – note the marked, linear uptake of the proximocaudal aspect of the right scapula. The diagnosis is a scapular fracture (confirmed with ultrasound).



One must consider additional methods, such as radiology, ultrasound, CT or MRI for establishing an etiologic diagnosis of a scintigraphic abnormality. Scintigraphy guides the radiographic study and determines which structural lesions are active.