Current and Future Diagnostic Means to Better Characterize Osteoarthritis in the Horse—Imaging

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Improvements in imaging are needed in order to detect subtle pathologic changes in osteochondral tissues typical of joint disease. Author's Address: Equine Orthopaedic Research Laboratory, Department of Clinical Sciences, College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO 80523. © 2001 AAEP.

1. Introduction

Although osteochondral damage is a well-recognized entity in equine joint disease, the detection of early or subtle disease is still poor. Osteochondral fragmentation and fracture, and osteoarthritis, are common in the horse, and diagnosis of these diseases usually occurs only after the disease has become established. Clinical perceptions and radiographic imaging are still the most commonly used techniques for diagnosis of osteochondral disease, yet osteochondral damage seen during arthroscopic surgery is usually more severe than that seen on radiographs. In order to completely characterize joint disease, the following measurements are necessary: 1) a measure of mechanical inputs into the joint; 2) a measure of tissue architecture and geometry; 3) a measure of tissue matrix properties, including measurement of material and biochemical matrix properties; and 4) a measure of the level of inflammation within the joint. A review of the current state of diagnostic capabilities for horses will be presented, and new techniques, such as gait analysis, CT, MRI and biomechanical modeling, will be presented.

2. Measurement of Mechanical Inputs

Clinical Examination

Subjective evaluation of an individual for pain has always been difficult because of confounding factors, the biggest being differences in observer scores and differences in a particular subject’s tolerance to pain. The same is true for a horse. Assessment of joint effusion, crepitus, range of motion, joint capsule thickening, and pain with flexion are currently used and subjectively graded by clinicians. Lame- ness grading guidelines have been established for horses, and are used extensively. Flexion tests are also commonly used; however, the reliability of such tests have been questioned lately.

Motion Analysis

Motion analysis has been employed for decades in human clinical medicine and veterinary research. The characteristics of limb movement and force can be determined, and abnormalities in these parameters can be characterized in patients with disease. For instance, it has been found in humans that impulsive loading often leads to
osteoarthritis. Data analysis currently involves sophisticated, expensive equipment and is often labor intensive. Therefore, most gait analyses in veterinary medicine occur in the research field.

Motion analysis systems, which combine data from force plates, EMG analysis of muscle forces, and kinematics, can provide sensitive information on an individual’s movements. These systems have been extensively studied in humans and are clinically used to evaluate an individual’s gait for abnormalities. Limb use and muscle forces play a large role in joint loading. For instance, joint forces detected by an instrumented femoral prosthesis in humans were twice as great as the ground reaction forces. Muscle force and coordination may also play a large role in equine joint disease; however, critical studies in the horse are lacking. Kinematic analysis of horses has been performed, the results of which should lead into studies of motion analysis. Diagnostic techniques that describe kinematics and muscle forces allow clinicians to identify those individuals with problems and modify their movement. A similar approach would be ideal for objectively characterizing movement and lameness in horses; however, the cost and labor intensiveness of such equipment might limit its use to referral practices.

Researchers in the Equine Orthopedic Research Laboratory have used a thin-film sensor system to evaluate limb loading in horses. This system can be attached to the bottom of a horse’s hooves to measure force distribution throughout the solar surface, or can be used much like a force plate for jogging horses across (Fig. 1). This Windows-based system is currently being evaluated against traditional force plate systems for accuracy and durability.

Computer Models

Computer models of joint loading are currently being studied in both humans and animals. The idea is to develop a model based on kinematic parameters, and compare that model to those developed from imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI). Muscle, tendon, ligament, and ground reaction forces and tissue properties can be input into the model. Once developed, imaging-based modeling can be performed so that subtle changes in joint geometry and loading can be detected. The ultimate goal of this research is to develop long-term models in which data can be continually added. The clinical goal is to develop patient-specific models in which abnormalities in loading and tissue response can be detected.

Researchers in the Equine Orthopedic Research Laboratory, in collaboration with the Orthopedic Research Laboratory at Columbia University and the Steadman Hawkins Sports Medicine Foundation, have performed intensive kinematic and MRI studies to develop a model of the equine carpus. Specifically, they have determined the center of force on joint surfaces in the carpal joints, and are currently correlating these data to those obtained from MRI scans (Fig. 2). The hope is that as technology advances, MRI and CT examinations can be performed on standing horses. Then, subtle irregularities in joint loading can be determined.

3. Measurement of Tissue Architecture and Geometry

Although radiography is currently the most widely used imaging technique for diagnosis of osteochondral disease, it is an insensitive method of diagnosis. Articular cartilage changes cannot be seen by radiography, and 30–40% change in bone mineral density is required before bone changes can be appreciated. In addition, summation effects due to overlap of bone requires multiple views to be taken; hence multiple 2-dimensional images are required for evaluation of a 3-dimensional structure. Because of these factors, mild changes in bone quality cannot be accurately identified and disease is often recognized after significant damage has occurred.

Although radiographs can be used to detect abnormalities associated with osteochondral disease, lack of sensitivity can prevent early and accurate diagnosis. For instance, articular cartilage thinning has been quantified by measuring joint width on radiographs of human knees. However, joint width can vary with age, standing position, and the particular joint that is imaged. Osteophytes have been associated with osteochondral disease, but their significance is unknown. Subchondral bone sclerosis and erosion have also been associated with osteochondral disease, but again, considerable

![Image](https://via.placeholder.com/150)

**Fig. 1.** Output from a thin-film measurement system showing both the intensity and distribution of forces across the sole of a horse’s hoof.
changes in bone mineral density must occur to see these changes. Laverty et al, in a study correlating radiographic and histologic changes in the tarsi of horses, found that radiographs were insensitive for detecting subchondral bone sclerosis and erosion when compared to histology.\(^\text{10}\) Significant amounts of osteochondral damage occurred prior to radiographic changes. Again, superimposition of structures can lead to misdiagnosis of sclerosis, such as superimposition of osteophytes that may appear as sclerosis.\(^\text{11}\) Similar results have been found in humans, in which radiographs have been shown to be insensitive for detecting bone pathology in the human knee.\(^\text{12}\)

Computed tomography has been used in a few instances to detect occult lesions in horses. For instance, Hanson et al have used it to find osseous lesions in joints in which radiographs did not reveal lesions.\(^\text{13}\) Benefits of CT are visualization of the area of interest in three dimensions (which alleviates superimposition) and use of the data to determine density patterns.

Density patterns of bone can be determined by three-dimensional modeling of CT images (CT osteoabsorptiometry, CTO). CTO has been performed on joints of human cadavers to evaluate its usefulness in detecting changes in subchondral bone density patterns.\(^\text{14,15}\) This technique allows 3-dimensional evaluation of the joint in any plane by CT image capture and digitization. Hounsfield units, which are the CT measure of bone density, are determined and coordinated into ranges, and then the ranges of densities are represented by colors. This color map is then superimposed over a 3-dimensional image of the joint surface to show a representation of the relative subchondral bone density.\(^\text{16}\) Using this technique, summation effects of superimposed structures are eliminated and a true 3-dimensional representation of the joint is given. Since it has been shown that stress distribution within an osteochondral section is related to the density pattern, it can be concluded that the subchondral density pattern is a representation of the loading history of the joint.\(^\text{16}\) Further investigation of CTO has also shown its value in assessing subchondral bone density and its relationship to articular cartilage damage. Eckstein et al have used CTO to evaluate subchondral bone beneath articular cartilage lesions on the patella, and found that articular cartilage lesions in the lateral aspect of the patella were over areas of dense subchondral bone, and that medial lesions were over areas of transition between dense and normal subchondral bone.\(^\text{17,18}\) They concluded from this study that articular cartilage overlying areas of dense subchondral bone endured increased stresses, and that articular cartilage overlying areas of transition endured shear stresses due to periodic loading. Both of these conditions induced articular cartilage degeneration; hence, assessment of subchondral bone density patterns might be a means of early diagnosis of osteochondral disease.

The use of CTO in horses has been limited. Thompson et al have reported on its use in a horse for determination of subchondral density pattern...
in the joint surface of proximal first phalanx.\textsuperscript{19}
Kawcak et al have also used this technique in pilot work and determined the subchondral density pattern of bones in equine carpal and metacarpophalangeal joints (Fig. 3).\textsuperscript{20}

Another imaging technique that has been investigated in horses is MRI. Results from human studies have shown that MRI is a sensitive and specific imaging technique for examination of hard and soft tissues in joints, and that it is as good as, if not better than, arthroscopy for detecting subchondral lesions.\textsuperscript{21} MRI is the best measure of articular geometry, and also adds the benefit of quantifying articular cartilage matrix properties using contrast enhancement.\textsuperscript{22}

MRI has been used oncadaver hooves and metacarpophalangeal joints of horses,\textsuperscript{23,24} and is now being used clinically at one institution.\textsuperscript{25} Martinelli et al have used post-mortem MRI in addition to other imaging modalities, including clinical examination, radiographs, nuclear scintigraphy, and arthroscopy, to evaluate an osteoarthritic metacarpophalangeal joint in a horse.\textsuperscript{26} They found that MRI gave an excellent image of articular cartilage erosion and underlying subchondral bone thickening, as well as subchondral bone thickening in areas of normal appearing articular cartilage.\textsuperscript{26} Kawcak et al have also used this technique to evaluate the effects of exercise on subchondral bone of horses, and found that it could image osteochondral damage such as small fragments (Fig. 4).\textsuperscript{27} Therefore, it appears that MRI is a sensitive and specific diagnostic technique for evaluating osteochondral damage.

4. Measurement of Tissue Matrix Properties, including Measurement of Material and Biochemical Matrix Properties

Nuclear scintigraphy has been found to be helpful in detecting cortical bone disease such as fatigue fractures in horses, but its use for detecting damage in subchondral bone is relatively untested. A nuclear scintigraphic image shows the physiologic distribution of radioisotope throughout the bone. Consequently, nuclear scintigraphy is more sensitive than radiographs in detecting early osteoarthritis in human knees.\textsuperscript{28} In humans, nuclear scintigraphy has been the best early predictor of progression of joint space narrowing in knees,\textsuperscript{29} and in some cases has been more sensitive than arthroscopy and MRI for detecting early and subtle subchondral bone pathology.\textsuperscript{30} However, one problem with nuclear scintigraphy is the inability to distinguish stress response due to subchondral bone adaptation from subtle osteochondral damage. Osteochondral fragments show up as discrete focal areas of increased radioisotope uptake.\textsuperscript{31} However, any remodeling change due to stress will also show increased uptake of radioisotope.\textsuperscript{32} Therefore, mild to moderate increases in uptake of radioisotope in the joints of horses, especially young, exercising horses, can lead to confusion. Regardless of the disease process, nuclear scintigraphy can be used as a good screening test to isolate areas of potential disease that may warrant further investigation. Beyond that, it is not specific enough to demonstrate a particular anatomical problem.

In order to eliminate some of the subjective requirements for interpretation of nuclear scintigraphy results, more objective means of assessment have become available. Using computer programs, areas of particular interest can be highlighted, the counts per pixel determined for that area, and normalized to the counts per pixel for a reference area within the same limb.\textsuperscript{33} This is of particular benefit because the distribution of radioisotope within an area varies between animals and between different regions within the same animal.\textsuperscript{33} Therefore, outlining an area of interest, such as the distal condyles of the third metacarpus, and normalizing the

**Fig. 3.** CTO images from the carpal and metacarpophalangeal joints of horses.
Fig. 4. Imaging of an osteochondral fragment on the distal aspect of the radial carpal bone. (a) An MR image of the distal aspect of the radial carpal bone shows the fragment (box). (b) A gross photograph of the fragment is seen. (c) A CT osteoabsorptiometry image of the fragment is seen (arrow).
Bone from osteoarthritic joints. The characteristics of articular cartilage collagen and proteoglycan can also be determined using this technique.35,36

Histologic properties of osteochondral tissues can also be assessed by optical coherence tomography, which can hopefully be used as an in vivo form of biopsy.37 Optical coherence tomography has also been studied in joints, and images correlate fairly well to histologic changes in tissues.37

In the future, clinicians will rely heavily on serum and synovial fluid markers of joint disease. At this time the markers are being validated and tested within clinical cases of joint disease in horses and small animals. The investigators are also assessing the use of joint models for assessing joint surfaces in horses. However, as time advances there will be a need for development of standing MRI to acquire images for modeling. Intraoperative assessment of osteochondral tissues is also being explored.

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Fig. 5. A scintigraphic image of a metacarpophalangeal joint in which the area of interest (a) is differentiated from a separate area (b).

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