1. Introduction
In the past, the medical profession realized that algorithms for certain patient's complaints and symptoms needed to be defined. Imaging modalities were increasing in type and number, creating confusion in determining the best method of examining patients. The number of diagnostic imaging choices and other testing procedures forced the development of the algorithms. There was a danger of patients being lost in the chaos of medicine in human hospitals.

A medical algorithm is any formula, score, scale, diagram, or computational technique that is useful in healthcare. Medical algorithms comprise a technology for medical decision support, with the potential to decrease time demands on clinicians, support evidence-based medicine, reduce errors, and help increase the quality while decreasing the cost of care. It is estimated that the biomedical peer-reviewed literature contains over 250,000 medical algorithms across all the specialties and subspecialties of medicine.¹

Equine medicine has not reached the complex situation that is present in human medicine, and most equine lameness/gait abnormalities are diagnosed and treated using a simple reasonable systematic approach. However, there is a decision-making process that must take place in examining lame horses. Lameness can involve one limb and one cause or have clinical evidence of multiple significant musculoskeletal abnormalities that may be secondary to one or more etiologies including, in some horses, infectious, metabolic, or neurological disease. In recent years, however, imaging options have increased in number and quality, and questions have arisen as to which of these modalities (or combinations) is the best application for a given situation. Understanding the specificity of a given modality is very important and implies a learning curve for each of us as practitioners.²

2. Imaging Modalities
Any imaging modality requires two learning curves before veterinarians can become proficient in its use. The first is to understand the modality and use it safely and effectively. Standard procedures need to be followed to maximize the information gained from the various modalities. Obtaining diagnostic images is the most important aspect of imaging. Close collaboration with technical support is necessary to ensure that equipment is maintained according to manufacturer’s recommendations to preclude image degradation over time or misuse. Some equipment requires periodic calibration to maintain
image quality. The second learning curve, and the most difficult, is learning to accurately interpret the images. Personnel need training in the specific modality to gain diagnostic proficiency. Reviewing the existing published literature and attending continuing-education courses, workshops, and seminars are recommended. Becoming proficient in all of the imaging modalities that are available is difficult and requires considerable time in training and experience. Proficiency in imaging requires knowing which modalities to use in different situations to gain the necessary information in the most efficient manner.

3. Digital Radiography

Digital radiography (DR) is well on its way to replace conventional film/screen combinations because of improved image quality, portability, and elimination of cassettes required to process films. The large number of heavy cassettes required to perform extensive field imaging is rapidly becoming a thing of the past. Notebook computers replace film and processors. Images can be evaluated as they are taken and viewed in the field, improving quality control and allowing for additional images based on the immediate information that is learned during the process. This eliminates return visits to take additional views and improves the studies because of the ability to correct positioning, adjust exposure, and eliminate motion. Tissues, normally of low contrast like soft tissues surrounding joints, have increased contrast with DR, producing wide-latitude images. This allows accurate bone and soft-tissue evaluation with a single exposure.

Even with the excellent latitude capable with DR, care must be taken to use proper exposure techniques to ensure excellent image quality. As with conventional radiography, the possibility exists to create over- or underexposed images if recommended techniques are not used. Repeating images is almost too easy using DR. It is not a digital camera. This ease of repeating the view to correct improper exposure parameters or positioning errors is a potentially dangerous practice. All of the radiation safety principles apply to any instrument emitting ionizing radiation and must not be abused. Care should be taken to obtain acceptable views on the initial exposure, including correct positioning and exposure settings, to avoid the necessity to repeat. Proper use of personal protective devices is still required. It is challenging with the small imaging plates to keep hands and fingers out of the primary beam. Cassette holders should be used whenever necessary. Personnel should not stand behind the small plate when taking views of the neck or skull from the contralateral side, for instance. Exposure to ionizing radiation must be kept to a minimum; it is deadly, and exposures are accumulative.

Viewing images on computers in the field improves the quality control and allows early diagnosis of critical injuries; however, the images should receive a final reading with post-processing image software in a more favorable environment to avoid overlooking pertinent information. Definitive evaluation of the images should not be made on the quality-control computer in the field. This definitive image-review recommendation applies to all modalities.

4. Computed Radiography

Computed radiography (CR) is well-established in many hospitals, both private and university-based. This is a cassette-based digital radiographic system with a laser processor more likely to be installed at a hospital or large clinic system. It is used similarly to a film-based system, with the difference being that the imaging cassette containing the sensitive plate is used over and over after being refreshed during processing. A number of cassettes are needed to avoid waiting for images to be scanned into the computer. As with DR technology, using proper exposure techniques is critical to successful imaging. Both digital technologies are an improvement over conventional film-based systems in all studies. The trend in private practices is to the DR systems because of their portability, ease of use, and image quality.

5. Diagnostic Ultrasound

There have been exciting advancements in the field of diagnostic ultrasound instrumentation since its use in horses started about 30 yr ago. Some improvements are small, but others have taken ultrasound to a new level. These advancements are the result of improvements in computer technology. One of the major changes is improvement in the portable machine image quality. There is less difference between portable and in-hospital units, because more powerful technology is now present in notebook-size machines. Improved computer technology has improved post-processing, allowing access to measurement tools, gain adjustments, and in certain machines, other adjustments after the study is completed. This decreases the time spent kneeling under horses, which everyone appreciates. Adjusting the gain as a post-process feature is very beneficial. In suboptimal lighting conditions, assessing the best gain can be difficult. This allows adjustment to a more correct gain after completion of a study, resulting in an image that more properly represents the structure of interest.

Virtual convex scanning is a method by which the normal rectangular linear field of view can be changed to increase the width of the far field. There is no compromise of image quality, and the increased far-field width is helpful, especially in the suspensory ligament origin where the ligament margins are likely to be cut off by the rectangular field of view. This function, when available, should be applied any time that far-field structures are wider than the linear field. Sagittal tendon views, how-
ever, should be made with the linear field that allows displaying long-fiber segments.

Extended field of view imaging is a method that allows structures longer than the normal field width to be scanned, freezing the image as the scanhead is moved to the next segment. It requires a steady hand and a constant probe speed to avoid distortion of structures. The entire superficial digital flexor tendon, for instance, can be scanned from the proximal metacarpus to the fetlock. The image will then shrink to fit the normal monitor viewing area after the scan is terminated. It can also be used to compare areas in close proximity. It provides the flexibility of tracking a lesion that is not necessarily confined to a single plane. The images display extended anatomic views that help explain the extent of an injury or a portion of anatomy to owners, trainers, and students. The extended view is valuable in visualizing longer segments of tendon- and ligament-fiber ruptures preparatory to and after using tissue-regenerative preparations.

Three-dimensional (3D) imaging allows for recording a cinematic rendering or a cine loop in cross-section, especially of tendons and ligaments. This block of tissue is saved and can then be post-processed to view multiple image planes to analyze its structure. This is an important time-saving feature that can be done after the exam is completed. The extent of fiber abnormality can be characterized more accurately using 3D imaging than attempting to capture multiple sagittal images. Care must be taken to capture satisfactory video clips for analysis. Significant changes in probe speed and angle can produce suboptimal clips that are difficult to evaluate. With practice, quality images can usually be obtained.

3D images are especially useful if tissue-regeneration products are used to treat tendon and ligament injuries. Saving a video clip and using the 3D technology is ideal for critical evaluation and documentation of tissue regeneration within injured tendons and ligaments. The ability to assess the linearity of all of the fibers by scrolling from the medial to lateral tendon margins eliminates the requirement to save multiple sagittal images. The technique ensures that critical areas are not missed by inaccurate placement of the transducer. Video clips can be archived as permanent records of the tendon-fiber status and reviewed at any time.

Ultrasound technology has now taken 3D imaging to the next level, rightly termed four-dimensional (4D) imaging. This process simultaneously displays the current imaging plane as well as other planes in real time during scanning as opposed to post-processing 3D images. It is the process used to make the ultrasound images seen on television and in magazines that show the facial features of unborn children in high detail. It has not yet been widely tested in horses, and its potential application for accurate musculoskeletal scanning remains to be proven.

Real-time spatial compound sonography or cross-beam scanning is a process by which the ultrasound beam is steered or has multiple angles of insonation, collecting information from different angles while the transducer remains in a single location. The multiple angles are combined or compounded to produce a single image during real-time scanning. This process reduces image artifacts and increases image quality. It improves tissue-plane definition and decreases speckle that is commonly seen in ultrasound images. An additional advantage specific to musculoskeletal imaging is a reported decrease in dependence on the angle of incidence for creation of an echo. Normally, imaging of tendons and ligament requires the ultrasound beam to be perpendicular to fibers to create the echogenic appearance considered normal. However, with steering of the ultrasound beam or multiple angles of insonation, it is more likely that one of these angles will be perpendicular to the structures of interest. Curved structures can appear more continuous with improved tissue-plane definition. A potential disadvantage is decreased temporal resolution. Compounding of multiple frames will increase motion artifacts. This is important with dynamic exams evaluating tendon motion. However, this function is usually easily turned on and off with the push of a button. In addition, the frame rate can be adjusted if motion blurring is observed during a dynamic exam. Although several studies have determined increased image quality resulting from real-time spatial compounding, controlled studies evaluating the effect on diagnostic accuracy in musculoskeletal imaging have not been performed.

6. Harmonic Imaging

Conventional ultrasound transmits and receives a sound beam of a specific frequency. The returning signal is less intense than the transmitted signal because of interaction with tissues. Harmonic imaging sends out an initial or fundamental frequency sound beam. This sound beam increases in frequency through interaction with the tissues. The sound beam compresses and expands tissue as it travels. The vibration created through this process distorts the sound beam and creates a harmonic frequency that is greater than the fundamental frequency. What is returned to the ultrasound machine for analysis is the harmonic frequency, which is usually two times the fundamental frequency. The machine produces an image from the harmonic frequency and ignores any returning fundamental frequency. Harmonic imaging improves spatial resolution but is depth-dependent. It is most effective at mid-field. In the near field, it is less effective, because the sound beam has not interacted enough with the tissue to create a harmonic frequency. In the far field, the harmonic frequency will be attenuated and not provide adequate information to the machine to create an image. However, in the mid-field, the sound beam interacts with
the tissue to create a harmonic frequency that can be transmitted to the transducer. It is important to note that the spatial resolution of the image is based on the harmonic frequency, not the fundamental frequency. Using harmonics, a frequency of 5 MHz may be required for the sound beam to reach the area of interest; however, the spatial resolution will be based on a frequency of 10 MHz, which is the harmonic frequency.

As image quality and software improvements are made in diagnostic ultrasound instruments for human use, veterinarians benefit greatly in adapting the newer systems for animal use. Images can be post-processed more effectively than in years past. Improvements in software allow 3D evaluations of tendons and ligaments in horses to more effectively evaluate the tendon-fiber structure. Extended-view scanning of tissues exceeding the field size allows valuable diagnostic information and teaching material to be gained during the examinations. Ultrasound is still the primary modality to image soft tissues in horses.

7. Scintigraphy

Equine scintigraphy has had a rebirth of use, because more systems are available in universities as well as private practices. Skill levels have improved the quality of images, and its use in solving lameness problems has been repeatedly shown. Scintigraphy is the most sensitive screening technique in medical imaging and should be an integral part of the diagnostic modalities in equine lameness practice. Time is the major drawback in performing scintigraphy, because whole-body studies require considerable effort in patient positioning and image acquisition. Working with the radioactivity is relatively straightforward, but compliance with state regulations is absolutely necessary. Personnel need to be trained to handle the radioactive material in a safe manner to avoid contamination. Complete records need to be kept documenting all of the information required by the state laws. The ability to survey the musculoskeletal system in horses exhibiting clinical signs referable to multiple sites allows clinicians to correlate increased radiopharmaceutical uptake (IRU) with the sites in question. In racehorses, detecting early stress remodeling, which often leads to potentially dangerous stress fractures, has been of extreme value at most major racetracks. Scintigraphy is also very important in detecting injuries or excessive remodeling of the entheses. This can be a source of pain and have IRU but have little response to direct palpation.

8. Computerized Tomography

Computerized tomography (CT) is in use in some private equine hospitals as well as universities. Serial slice-imaging techniques in CT complement conventional radiographic imaging. Unique software allows post-processing that enhances the images and provides additional information. It is of particular value in complex bone injuries and skull imaging. Use of contrast agents with CT imaging has improved the examination of distal-limb abnormalities. Anesthesia is required to perform the studies, patient size is a problem, and like other modalities requiring general anesthesia, it should be used when there is a high expectation of increasing the yield of diagnostic information.

9. Magnetic Resonance Imaging

Magnetic resonance imaging (MRI), the most recent modality to be used extensively in horses, has greatly expanded the list of differential diagnoses, especially in injuries within the hoof capsule, by complementing and expanding information from other modalities. Because MRI is not a screening instrument, lameness evaluation has become more important than before in determining where problems are located. MRI is expensive, and its use should be implemented with a high expectation of adding important information to the diagnosis. Examining multiple anatomic sites requires considerable time to acquire the necessary imaging sequences. Standing magnets are extremely useful in evaluating tissues, especially because of the high incidence of foot and pastern injuries causing lameness. Its use obviates the necessity for general anesthesia, and the modality is more safe and cost effective in performing follow-up examinations to monitor healing progress. However, more proximal joints may require general anesthesia to eliminate motion during the studies. Obviously, the larger field-strength magnets do boast superior imaging quality for certain evaluations. General anesthesia is required for its use in horses, and as with CT, it should be used when there is a high expectation of increasing the yield of diagnostic information. MRI is the modality of choice for examination of the hoof structures.

10. Thermography

This imaging modality has been in the inventory for years and has, in the author’s experience, not been a major imaging modality in the clinical definitive diagnosis of equine lameness. This is especially true in referral practices where scintigraphy, because of its greater sensitivity, is the method of choice for skeletal surveys. Thermography is an effective screening modality and does provide valuable information that correlates with areas of inflammation causing increased blood flow in horses. It may serve as a starting place in the physical examination procedure. Its findings provide the indication to further examine the affected sites with other more specific modalities.

11. Algorithms in Veterinary Medicine

Indications

The same problem faced by the medical profession in recognizing the importance of algorithms in clinical
medicine is present in all facets of veterinary medicine today but to a lesser degree in equine musculoskeletal-injury diagnosis. There are many diagnostic and therapeutic options available to veterinary clinicians that require a systematic approach to problem solving. The methods need to be effective in providing accurate diagnostic information as well as cost effective. Equine musculoskeletal injury diagnosis is no longer simply an observation, a local block, and an X-ray leading to a treatment. Simple algorithms can be used to investigate more complex musculoskeletal problems in horses. It is becoming common, however, to perceive that the most complicated and detailed imaging modality should be used, even initially in some cases. This is impractical in most cases. Valuable diagnostic information gained from systematically moving from simple to more complex imaging modalities may obviate the need to enlist more specific expensive techniques.

An algorithm obviously has a starting point, a series of diagnostic procedures, results, and observations hopefully culminating in a successful treatment. The algorithm can be graphically represented as a decision tree, where each branch indicates a step in the diagnostic process or medical-record entries documenting the process. Steps in the algorithm may include laboratory analysis, treatments, periods of rest, and observation, etc., and they can be valuable in very complex procedures. The following discussion addresses the use of the algorithm-thought process in decision making in equine lameness diagnosis. The historical information (including the effects of any therapies), clinical examination and observation findings, and imaging decisions and their results make up the decision tree that is formed to attempt to determine the etiologies of lameness or gait abnormalities.

**First Encounter**

The starting point in the process is most important in forming the relationship between the veterinarian and trainer and/or horse owner. Valuable information regarding the status of the horse is disclosed during discussion of the problem(s) that is essential to initiate a process leading to a solution. The importance of obtaining a complete history of the horse’s status cannot be overemphasized. This should include breed, age, use, performance records, circumstances of injury, duration of signs, treatments, etc. This information is paramount to beginning the task of problem solving. Clues to the etiology of the injury usually are suspected from the discussions. It is absolutely essential to listen carefully to the people who know the horse. Their observations and opinions of the problem as they see it form the initial thought processes for the investigation. During this time, it is necessary to ask pertinent questions regarding the horse’s performance. Prior clinical information regarding prior diagnostic attempts and response to any treatment should be disclosed. Results of prior radiographs, ultrasound scans, scintigraphy scans, MRI, thermography, etc. should be reviewed. If possible, any videos of past shows, races, etc. that may help show the problem should be reviewed as well. Therapeutic regimens and their affects, if any, on the condition need to be discussed. Expectations for the future of the horse should be included in the discussion. From this information-gathering process, an initial list of differential diagnoses can be formulated.

**Clinical Examination**

The importance of the physical examination of the horse cannot be overemphasized. It is at the top of the decision tree and will shape the events and decision making as the process progresses. The examination should include a passive examination, including palpation and responses to various flexions or manipulations. After this, observation at the walk, trot, and lunge should be done, if possible. The horse should be observed under saddle with a rider (or driven), unless the horse’s status or disposition makes it potentially unsafe. Videotaping the lameness for future reference is recommended, because it allows for multiple reviews and comparisons in the future. The first branches of the diagnostic tree have been identified with this information. The procedure may stop at this point, depending on findings, or it may progress to a diagnostic plan. It is important that the examiner be convinced that the patient shows an abnormality (i.e., lameness) and other means); however, because of client pressure and history, such examinations, including ancillary examinations, are known to take place, which may result in providing incorrect information.

**Diagnostic Plan**

**Imaging**

This plan should be based on the initial findings and may include the following steps:

1. Localization of the source of pain/discomfort can be accomplished in a variety of ways (manipulation, digital pressure, hoof testers, and other means); however, regional or more specific (intra-thecal, for example) anesthesia should be followed by observation in hand or under saddle (safety of the horse and rider need to be considered depending on the situation).

2. Most lameness examinations require that some type of imaging be performed. Radiography is recommended commonly as the first step in imaging, unless the horse obviously has a soft-tissue swelling of a tendon or ligament where ultrasound would be more practical. Radiography is the most familiar modality and is a good starting place, allowing evaluation of bone and the surrounding
soft-tissue planes. It provides a graphic history of the bone’s response to mechanical forces and the morphologic damage that they have caused. If further information is needed from the surrounding soft tissues, ultrasonographic examination should be performed to complement the radiographs. If this level of investigation provides satisfactory information that sufficiently explains the abnormality to the veterinarian and owner/trainer, the process may stop at this time, and a treatment plan may be formed.4,5

3. If satisfactory answers are not gained from the above, scintigraphy could be used to survey the tissues. If the problem limb or limbs are defined from the initial examination, scintigraphic examination makes the most sense to survey the tissues. During scintigraphy, the soft-tissue phase should be performed over the area of interest. The bone phase can be limited to the same area of interest, or it can include more of the musculoskeletal system to rule out remote areas of abnormality that may be contributing to the clinical signs. Any areas of IRU should be documented, and appropriate images should be captured for review. The trend in some practices today is to routinely evaluate the top line, including the cervical and thoracolumbar vertebrae and pelvis (including the sacroiliac joints), especially if no convincing findings are made in the regions of interest. Some clinician’s routinely examine the entire musculoskeletal system, including the skull. In my experience with a large number of horses with remote anatomic structures causing secondary lameness, I recommend imaging the cervical spine, thoracic and lumbar dorsal spinous processes, and sacroiliac joints. The diagnosis tree may stop at this point if the information is adequate and a diagnosis is made. If the addition of scintigraphy reveals other sites of IRU, additional radiographs or ultrasound may be indicated. Ultimately, all areas of abnormal IRU need to be correlated with the clinical findings. Asymmetric IRU should be viewed with suspicion.

4. If IRU is found in structures within the hoof capsule, for example, and no overt evidence of a primary cause of the lameness is found elsewhere, the process may stop at this level. For instance, if navicular bone uptake is present during scintigraphy and medullary navicular bone sclerosis is present on radiographs and is accompanied by flexor-surface erosion of the navicular bone, the decision to treat the horse may be made. In this scenario, however, many owners or trainers will opt to pursue additional imaging in an attempt to formulate a more accurate prognosis for the future. In this scenario, for those structures within the hoof capsule, MRI is recommended to obtain the most accurate diagnostic and prognostic information. The foot examination can be efficiently performed in a standing system to confirm the navicular bone changes and rule out concomitant involvement of other structures, especially the deep digital flexor tendon and impar ligament as well as other structures within the foot.

From the above diagnosis-tree example, a diagnosis or short list of differential diagnoses can be made to determine a treatment plan. This may be apparent at any step in the process but may require the gamut of diagnostic imaging options to make the final diagnosis and prognosis, depending on the circumstances and the owner’s desires. Significant findings with unfavorable prognoses may lead to retiring the horse, depending on the age and circumstances.

12. The Algorithm Endpoint

The endpoint should result in a diagnosis or at least a short differential list of diagnoses and prognoses at whatever level it progressed. The diagnostic information gained from the process should lead to a treatment plan. It is not within the scope of this paper to discuss the various therapeutic options that are available; however, cost and practicality must be factored in and may influence the outcome. Some owners/trainers may want to try a conservative approach, including rest, for instance, before investing in expensive therapies.

Many factors must be considered at the decision levels of the diagnostic algorithm. For instance, it may be impractical to perform a series of costly procedures in an older horse if the lameness has a guarded prognosis. Severe tendon or ligament injuries with unfavorable prognoses in racehorses, for instance, may force retirement that may be more cost effective. First-aid therapy to keep the horse comfortable in retirement may be enough. Use of expensive therapeutic regimens may not be indicated if the outcome is questionable.

Common sense should intervene if the clinical findings suggest that a blind pathway has been chosen to try and solve the horse’s problem. Investigating a primary inciting cause of the problem may prove fruitful. For instance, if radiographs and ultrasound or even MRI findings do not correlate with painful sites, scintigraphy may be indicated in an attempt to locate a cause. It should be remembered that horses may have pain from abnormal weight-bearing that can lead to a lameness that can be influenced by regional anesthesia. It follows that the asymmetrical weight-bearing can cause an injury that will also respond to regional anesthesia, and lesions may be found. Neurological horses fall into this category and may have clinical lameness
caused by injury or referred pain. If a remote cause is not considered, therapy will be ineffective.\textsuperscript{5}

If confusion persists after attempts to solve a lameness problem are tried in a systematic approach, it is beneficial to refer the results to a recognized consultant. This type of collaboration is common and may involve sending the images for interpretation, arranging to have the horse examined for a second opinion, or both. The primary goal is to efficiently define the causes of musculoskeletal abnormalities producing lameness, which can lead to the application of efficacious therapeutic measures that restore function. It is my opinion that most active equine athletes that are or have been lame have multiple rather than singular problems and thus, both the diagnostic and therapeutic success are dependent on defining the entire clinical picture. It is clear that today’s horse owner/trainer is desirous of every increasing diagnostic sophistication; however, it is helpful to educate as often as possible. Situations are relatively common where horse owners have foolishly spent significant sums of money based solely on inappropriate marketing of a given diagnostic imaging modality. It is or should be evident that the sustainability of a trusting clientele is based on providing accurate information, including the correction of misguided information that a given form of imaging will do all and tell all.

\textbf{References and Footnotes}


\textsuperscript{a}LogiqVue, GE, Fairfield, CT 06828.

\textsuperscript{b}SieScape, Siemens, Berkeley, CA 94704-1074.