ULTRASOUND TISSUE CHARACTERIZATION

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Overstrain injuries to the superficial digital flexor tendon (SDFT) are amongst the most common musculoskeletal injuries for all athletic equine disciplines but account for a significant amount of wastage in the Thoroughbred (TB) racehorse.[1] Treatment options are numerous and varied, but all have a couple of things in common: time out of training, expense, and no guarantee of success.

It makes sense then, that prevention of injury should always be the goal. Failing that, a method to optimally guide rehabilitation is needed. Unfortunately, limitations of current imaging diagnostics have restricted their use for accurately monitoring the tendon. However, a new ultrasound technology, called ultrasound tissue characterization (UTC), may get us one step closer to achieving the goals of injury prevention and optimal rehabilitation.

WHAT WOULD THE IDEAL TENDON IMAGING MODALITY ALLOW US TO DO?

- Monitor the effects of exercise on the tendon
- Early detection of overstrain injuries
- Be able to stage the lesion – i.e. determine the level of degenerative change within the tendon structure
- Fine tune therapy
- Guide rehabilitation

WHY ARE TENDON INJURIES SO TRICKY?

- Normal healthy tendon is made up from aligned organized tendon bundles. Deterioration of this structure ranges on a spectrum from complete disruption (core lesion) to more minor changes, but all affect the ability of the tendon to function optimally.
- Degenerative changes within the tendon matrix are not uniform – meaning that not all overstrain injures to the SDFT are represented by the same level of deterioration or structural change.

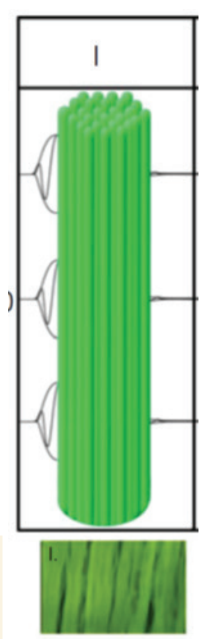


Figure 1: Functionally normal, healthy aligned tendon bundles.
Image courtesy of Hans van Schie.

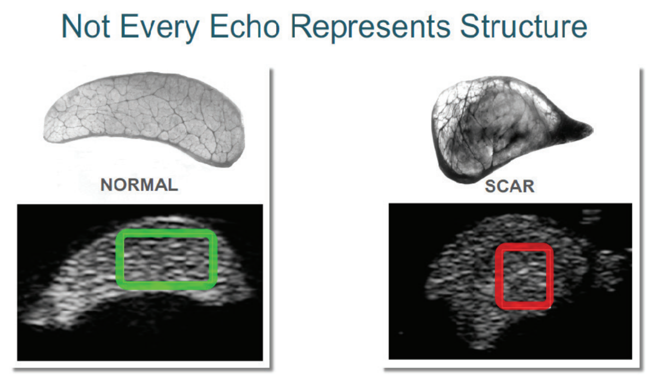


Figure 2: On the left is a completely normal tendon, and on the right is one with an extensive scar. The scar contains no normal structure, but, on the conventional greyscale image, lots of echoes can still be seen. It is important to realize that there is often little relationship between grayscale and structure, that mess generates echoes too and that a 2D image cannot fully represent a 3D structure.
Image courtesy of Hans van Schie.

- This means there is not a one size fits all pathology or diagnosis and, therefore, there cannot be a cure-all treatment.
- Most tendon injuries have a sneaky onset with tendon degeneration developing initially without clinical signs. Often by the time a problem is recognized, tendon matrix degradation has already begun.
- Staging the structural integrity of the tendon or classifying the extent of structural deterioration present is, therefore, imperative; not only for optimal therapy selection and appropriate rehabilitation guidance, but also if prevention of injury is to be achieved.

WHY ISN'T CONVENTIONAL ULTRASOUND ENOUGH?

- Unfortunately, although conventional ultrasound has historically been used to evaluate equine tendons, limitations have restricted its ability to accurately monitor tendon structure, predict injury, or guide rehabilitation.[2]
- Clinical improvement is usually not accurately correlated with changes in imaging status using conventional ultrasound, especially in the later stages of healing, with conventional ultrasound not demonstrating enough sensitivity to determine the type of tendon tissue under investigation.[3]

- Although conventional ultrasound can easily demonstrate the presence of a core lesion when it first appears, by approximately two months post injury its capacity to provide information regarding the health of the tendon is limited. The ability of conventional B mode ultrasound to reliably evaluate and monitor the SDFT following the initial acute period is restricted by many factors including: its inability to accurately interpret the integrity of the underlying tendon tissue; its reliance on operator skills and the inherent lack of ability of a 2D ultrasound image to fully decipher a 3D tendon structure (Figure 2).[4]

WHAT IS ULTRASOUND TISSUE CHARACTERIZATION?

Ultrasound tissue characterization is a relatively new technique intended to alleviate some of the problems encountered with conventional ultrasound by improving objective tendon characterization. It does this by standardizing instrumental settings, by providing a 3D reconstruction of the tendon, and by classifying and then quantifying tendon tissue into one of four color-coded echo types based on the integrity of the tendon structure.[5]

It can assess, in detail, the structural integrity of the tendon; it can discriminate a variety of pathological states and it is sensitive enough to detect the effect of changing loads on the tendon within days. [6,7]

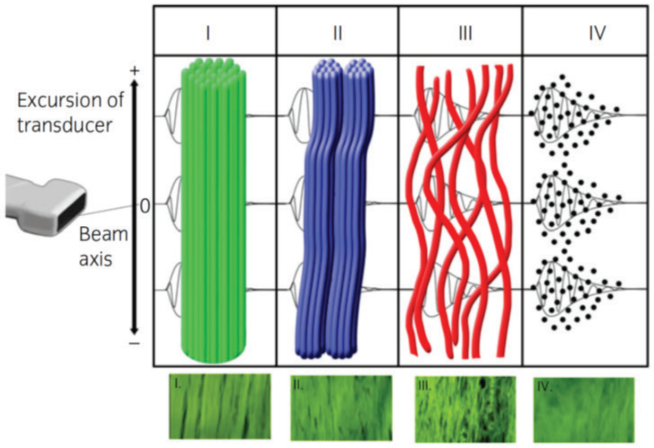


Figure 3: Color-coded, ultrasound tissue characterization echo types representing the stability of echo pattern over contiguous images related to tendon matrix integrity.
Image courtesy of Hans van Schie.

WHAT DO THE COLORS MEAN?

Ultrasound tissue characterization algorithms quantify the continuity of echopatterns over contiguous images by analyzing the intensity and distribution of relative grey levels of corresponding pixels.

Green (Type I echoes) are normal, well aligned, and organized tendon fascicles and at least 85-90% of this echo type should be found in a healthy tendon (SDFT). Blue (Type II echoes) are areas of wavy or swollen tendon fascicles. They can represent remodeling and adapting tendon or inferior repair. Red (Type III echoes) represents fibrillar tissue (the smaller basic unit or building block of tendon). This echo type can represent partial rupture of tendon where they reflect breakdown of normal structure, or they can represent initial healing as the tendon begins to rebuild. Black (Type IV echoes) are areas of cells or fluid and represent core lesions where no normal tendon tissue exists.

Type I and II echoes are generated by structural reflections from larger structures (such as intact fibers), while Type III and IV are 'interfering echoes' from smaller entities below the limits of spatial resolution (Figure 3).[5]

HOW IS ULTRASOUND TISSUE CHARACTERIZATION CURRENTLY USED?

The aim of ultrasound tissue characterization is not to replace conventional ultrasound but, on the contrary, it is recommended to perform an evaluation with both conventional B mode ultrasound and ultrasound tissue characterization to achieve a complete picture of tendon health.

Currently, it is used successfully in elite human athletes, such as NBA and soccer players, to monitor the health of their tendons (Achilles tendon and patellar tendons) and to guide exercise regimens post injury.[8] In the equine field, it is used predominantly in elite sport horses in Europe, as a part of routine maintenance evaluations to direct exercise, to monitor tendon health, and guide rehabilitation following an injury.

Figure 4: Ultrasound tissue characterization tracker frame with attached ultrasound probe and built in standoff.
Image courtesy of Hans van Schie.

Figure 5: Ultrasound tissue characterization machine positioned over the SDFT. It is held with gentle, steady pressure in this position for the 45 seconds it takes for the probe to move down the tendon and collect images. Horses need to stand still with all four limbs fully weight-bearing during this time.
Image courtesy of Hans van Schie.

HOW DOES IT WORK?

UTC consists of a standard linear array ultrasound probe mounted onto a motorized tracking device with a built-in stand-off pad. Due to the sensitivity of the equipment, meticulous skin prep is required, and limbs typically need to be clipped to obtain good quality images (Figure 4).

The probe moves non-invasively and automatically down the tendon from proximal to distal over a 12 cm scanning distance, which takes approximately 45 seconds (Figure 5). As it does so, transverse images are captured at regular distances and stored in real time in a high capacity laptop for processing. Images are automatically recorded every 0.2 mm to generate a 3D tendon volume made up of 600 images. This precise spatial 'stacking' of images is simply not possible to achieve with conventional ultrasound and is fundamental to the ultrasound tissue characterization technology (Figure 6).

The tendon volume can subsequently be used for visualization of the tendon in 3D, for tissue characterization (to determine the structural composition of the tendon), and for quantification of tendon matrix integrity (Figure 7). The color-coded echo types provide semi-objective information regarding the integrity of the tendon matrix and reflect the underlying tendon health. Ultrasound tissue characterization can discriminate between healthy normal tendon, adaptive/remodeling tendon, and injured/healing tendon, often in cases where conventional ultrasound appears unremarkable (Figure 8).

The key to this technology is to perform successive evaluations. This allows comparison of differences in tendon structure between scans. Such consecutive examinations, along with clinical data and history, allow veterinarians to determine if a tendon is static, adaptive, healing, or degenerating. This information enables changes in training intensity to be made accordingly (Figure 9).

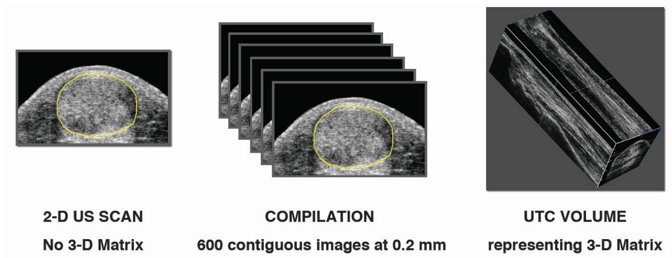


Figure 6: The stacking-up of regular transverse ultrasound images to create a 3D rendition of the tendon.
Image courtesy of Hans van Schie.

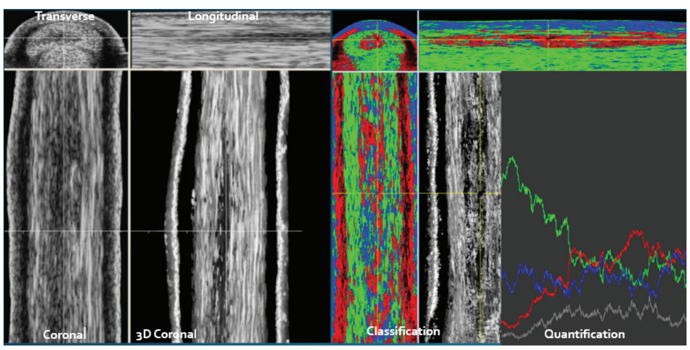


Figure 7: Grey scale and colored images of the tendon in transverse, longitudinal, coronal, and 3D coronal. To generate the picture in color, the computer classifies and quantifies tendon structure into one of four color-coded echo types representing structural integrity.
Image courtesy of Hans van Schie.

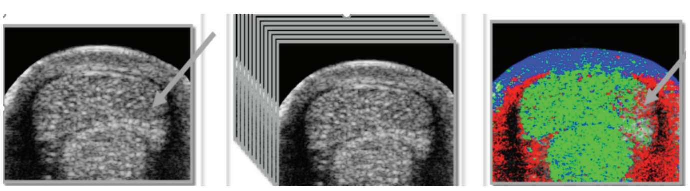
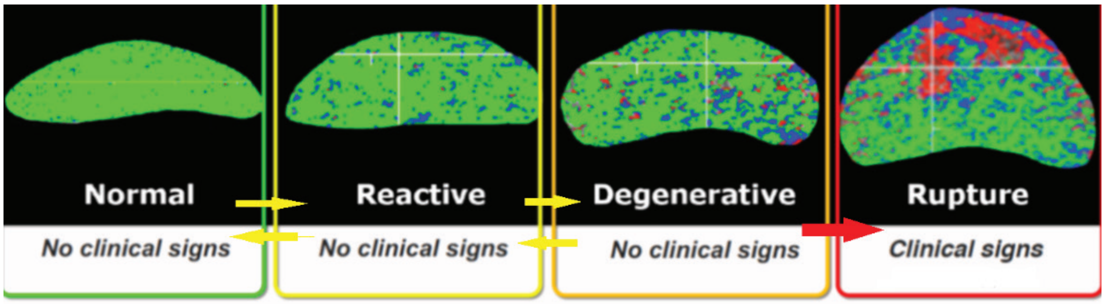


Figure 8: The image on the left shows a conventional, grey scale ultrasound image that is unremarkable. Conversely, the image on the right depicts an ultrasound tissue characterization image of the same tendon and shows an area of suspected injury, see red area denoted by the arrow.
Image courtesy of Hans van Schie.



Within 6 months substantial matrix degradation, initially without clinical signs.

Figure 9: Image from an elite show jumper depicting tendon matrix degradation prior to clinical signs.

To the left, the 'normal' SDFT scanned while training out of season in light exercise. Five months later, at the start of the season the horse showed no clinical signs, but ultrasound tissue characterization images already showed a mild increase in Type II (blue) and Type III (red) echoes. This tendon is in a reactive phase, which can be reversible when managed appropriately. Despite warning, the rider continued full training. Six weeks later: there is now a striking increase in Type II (blue), Type III (red), and Type IV (black) echoes. The tendon matrix is now in a degenerative phase. There are still no clinical signs and the rider continues competing. Six weeks later, after a competition, the horse now has clinical signs and there is a 'rupture.'

This pre-clinical information has the potential to provide opportunity for early intervention and a change in exercise level prior to clinical injury. Research is ongoing to validate any predictive capabilities this technology may have and to develop optimal evaluation programs. Preliminary research has shown that while an acute increase in Type II echoes may be reversible within four days, an increase in echo Type III and IV may not be reversible within that time frame and may take 4-12 weeks, if reversal happens at all.
Image courtesy of Hans van Schie.

LIMITATIONS

- In most cases, the limb will need to be clipped to obtain diagnostic images.
- Horse and operator need to be very still – even the slightest movement can cause erroneous results.
- It is advisable to perform three scans of each tendon to reduce the likelihood of movement artifact in any single scan.
- Training is needed not only for image acquisition but also for image interpretation. There is an intense and steep learning curve undertaken by the user in order to allow the technology to perform optimally.

RESEARCH

As ultrasound tissue characterization semi-quantifies tendon structure, it is an ideal research tool to objectively assess different rehabilitation modalities by monitoring tendon integrity. Published equine research has reported correlation of ultrasound tissue characterization echo types with histological studies. Ultrasound tissue characterization was found to be able to distinguish between different tissue types (normal, granulation, and fibrotic tissue), where basic grey level statistics could not.[9,10]

Numerous, peer-reviewed research studies exist documenting the ability of ultrasound tissue characterization to evaluate and monitor tendon both in human and equine athletes.[5,7,11,12] Ultrasound tissue characterization has been reported to be highly reproducible with both inter and intra-observer agreement levels being remarkably high.[7,10,11]

RELEVANT STUDIES

A normal and transient response of tendons to load application has been suggested in basic scientific research. *In vitro* and *in vivo* studies have shown the expression of anabolic and catabolic proteins to change within hours of loading and then return to baseline within 72 hours.[12, 13] However, the ability to detect such subtle changes in tendon structure in response to exercising loads has not been possible using conventional imaging and this makes the ultrasound tissue characterization research in both humans and horses extremely exciting.

Ultrasound tissue characterization has been used to detect these short-term temporal responses to load in the Achilles tendon of human athletes and in the superficial digital flexor tendon of racehorses. In both species, a loss of aligned fibrillar structure was observed 48 hours after maximal load with baseline levels returning 3-4 days later. On UTC images, these changes were documented as a decrease in Type I echoes (normal and aligned tendon bundles), an increase in Type II echoes (swollen and wavy bundles), and a constant level of degenerative indicators such as Type IV echoes.[7,12] In both studies, all cases consisted of clinically normal individuals with no evidence of clinical decline or degenerative change on UTC examination and all changes were documented to be reversible in nature. For these reasons, the transient increase in Type II echoes, in response to increasing loads, was considered adaptive rather than degenerative, with both authors citing an increase in water content as a possible reason for the transient change in echo types.[14]

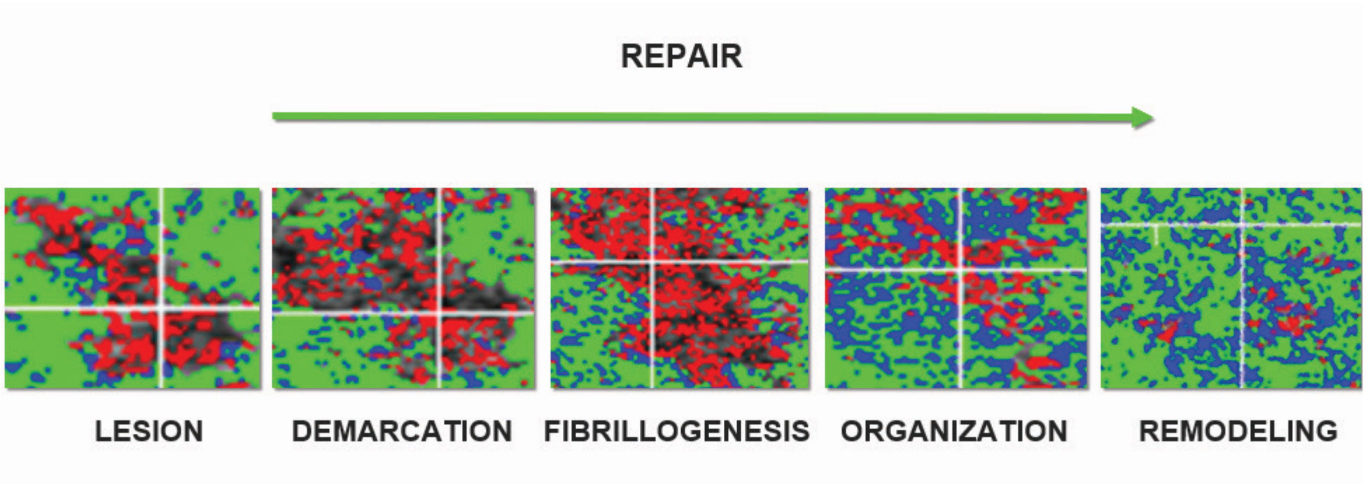


Figure 10: Suggested timeline of repair visualized using ultrasound tissue characterization. As healing progresses, the proportion of red and black echoes decrease and blue and green increase.
Image courtesy of Hans van Schie.

ADDITIONAL RECENT EQUINE RESEARCH

A second Thoroughbred (TB) racehorse study performed by our practice, reported a reference range for normal juvenile TB SDFT ultrasound tissue characterization values and demonstrated changes in SDFT characterization over the first six months of training.[11] It demonstrated the ability of ultrasound tissue characterization to non-invasively monitor physiological changes in maturing TB tendon. The study highlighted differences between tendons in the dominant versus nondominant limbs and, subsequently, tendon adaptations to loading during this early training period.[11]

HOW CAN THIS TECHNOLOGY BE USED IN THE RACEHORSE?

Rehabilitation:

It is widely accepted that the complete removal of load on tendons post-injury is deleterious for tendon health, and complete removal of exercise is only advocated in the very acute inflammatory phase following a tendon injury. Appropriate, progressive loading of the tendon is desired to stimulate remodeling and healing, and this is where ultrasound tissue characterization is proving to be most useful.

Typically, an exercise regimen post-injury follows a generic format using clinical signs, conventional ultrasound, and the calendar as the only methods of assessment. However, as most early tendon degradation is silent and conventional ultrasound struggles to decipher the integrity of the tendon, unless a lesion is present, it has traditionally been difficult to precisely guide exercise regimens during rehabilitation.

By providing real time information regarding the integrity of the tendon matrix, ultrasound tissue characterization allows veterinarians to take advantage of the limited window of opportunity that exists for appropriate tendon remodeling after injury. By mapping the ultrastructure of the healing tendon, and its remodeling response to exercise at each step in the rehabilitation regimen, it allows optimization of the most vital tool we have in our rehabilitation arsenal: exercise.

While ultrasound tissue characterization technology is groundbreaking in its ability to non-invasively evaluate tendon structure and aid in tendon rehabilitation, it must be remembered that once a tendon is injured, it will always be inferior to uninjured tendon. Scar tissue will always be scar tissue. So, while green echoes are the goal (normal and aligned tendon bundles), and represent success for a rehabilitating tendon, they still just represent scar tissue, albeit aligned appropriately and in the best state to combat the strains of training and competition. This technology doesn't remove the risk of reinjury in the injured tendon, and it doesn't provide information regarding the biochemical make up of the lesion or the tendon. It simply tells us if the tendon is structurally normal and, by doing so, it improves our ability to monitor and guide healing. It provides veterinarians the best opportunity, currently, to adjust and tailor exercise regimens for the specific needs of the individual tendon and horse, allowing for informed decisions regarding the tendon's capacity for performance (Figure 10).

THE FUTURE

Injury Prediction?

While the current scientific literature seems to support the use of ultrasound tissue characterization to guide rehabilitation and monitor the effects of changing loads on the tendon during training, numerous anecdotal accounts from clinical practice, both human and equine, also report the ability of ultrasound tissue characterization to warn of impending injury. Although, human research is currently ongoing to confirm this, equine research is needed to determine the specifics of any predictive capabilities the technology may have. For now, however, the evidence suggests that ultrasound tissue characterization can reliably and accurately be used to help guide rehabilitation of injured tendons, in both humans and horses, with the potential for a more successful return from injury.

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Dr. Sarah Plevin is a sports medicine specialist and partner at Florida Equine Veterinary Associates. Originally from the United Kingdom, she graduated from Glasgow Veterinary School in Scotland. After, completing a surgical internship in Ocala, Florida, she went into general practice for a couple of years before undertaking a lameness fellowship and then pursing specialist qualifications. She is double boarded with the American Association of Veterinary Practitioners and the American College of Veterinary Sports Medicine and Rehabilitation. Dr. Plevin has also attained status as an equine sports medicine specialist from the Royal College of Veterinary Surgeons and is certified in veterinary acupuncture. Currently, Dr. Plevin devotes most of her time to clinical research and leads the research department at FEVA, where her focus is on preventing injuries in the juvenile TB racehorse. She has presented her work both nationally and internationally. Outside of work, Dr. Plevin is a keen swimmer and enjoys all outdoor activities. She is married with three young children and enjoys traveling extensively throughout the world with her family.