M.E Baker[1], L.E Kershaw[2], A. Carstens[3], C.R Daniel[1], H. Brown[1], S. Roberts[4] and S.E Taylor[1]

[1]Royal (Dick) School of Veterinary Studies and The Roslin Institute, The University of Edinburgh, UK
[2] Centre for Cardiovascular sciences and Edinburgh Imaging, The University of Edinburgh, UK
[3] School of Animal and Veterinary Sciences, Faculty of Science, Charles Sturt University, New South Wales, Australia
[4]Hallmarq Veterinary Imaging Ltd, Guildford, Surrey, UK

T_2 Mapping of Cartilage in the Equine Distal Interphalangeal Joint using 0.27 T and 3.0 T MRI

Introduction

Osteoarthritis (OA) is a common musculoskeletal disease of the horse causing pain, lameness, poor performance and premature euthanasia. The prevalence is greater than 50% in horses >15 years and over 80% of horses >30 years [1]. The distal interphalangeal joint (DIPJ) is a common site for OA development. Currently, there are no diagnostic tools available for early detection of equine OA which has led to exploration of quantitative MRI techniques that detect tissue damage before morphological change is apparent [2]. During cartilage deterioration the collagen and proteoglycan content decreases and is replaced by water, increasing cartilage T2 [2]. Low field standing magnets are the most widely available system in UK equine practice and previous work has validated a T2 mapping sequence on a low field strength (0.27 T) magnet however, this has not been verified against the gold standard measurements at high field (3.0 T).

Objectives

I. To evaluate the mean T2 relaxation time in sections of cartilage with varying levels of pathology using low (0.27 T) and high field (3.0 T) MRI
II. Verification that the low field methodology generated the same T2 value as the high field system

Methods

- A 0.27 T open system (Hallmarq Veterinary Imaging Ltd©, Surrey, UK) and 3.0 T clinical scanner (MAGNETOM Skyra 3T, Siemens Healthcare, Erlangen, Germany) was used to scan 9 ex vivo Thoroughbred racehorse DIPJs using a 2D multi echo spin echo T2 mapping sequence (Table 1).
- After imaging the DIPJs were opened, gross changes observed (Figure 1) and samples were taken from the surface of the second phalanx (P2) and third phalanx (P3).
- Cartilage sections were stained with haematoxylin and eosin and safranin O. Sections were graded twice using the OARSI scoring system.
- Fiji ImageJ software with the MRIAnalysisPak plugin was used to calculate T2 maps. ROIs were drawn over P2 and P3 articular cartilage on the TE=22 ms image slice for low field images (Figure 2) and the TE=14 ms slice for high field images which matched the histological sample location. ROIs were transferred to the T2 maps to calculate mean T2. This was repeated twice.
- Correlation between low and high field mean T2 measurements was determined using Spearman's rank correlation ($P<0.05$).
- The intra-rater variability for T2 measurements was quantified using the intraclass correlation coefficient (ICC) in R version 4.1.2 using the 'psych' package in a two-way mixed effect model.
- The intra-rater variability for OARSI grades was analysed using Cohen's weighted kappa in R version 4.1.2 using the 'irr' package.

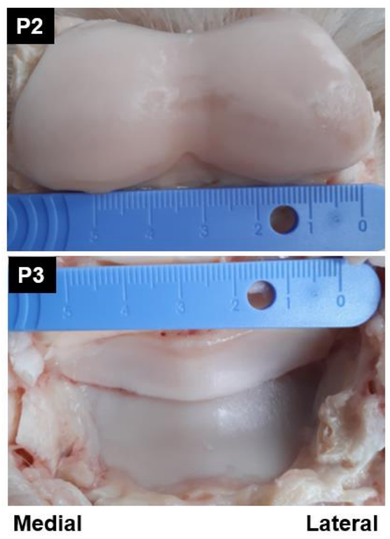

Figure 1. Photographs demonstrating the gross pathology of P2 and P3.

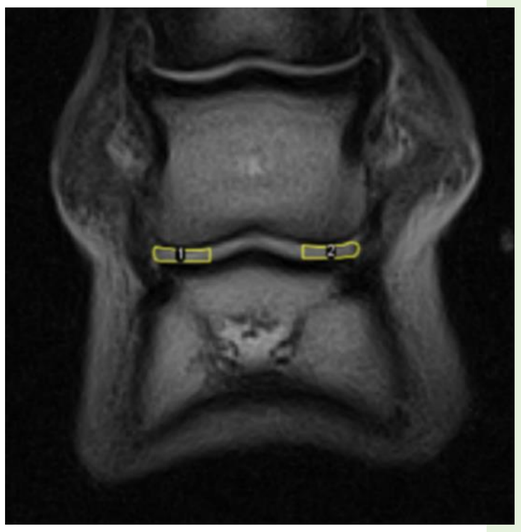

Figure 2. Example of a left fore foot dorsal TE=22 ms image slice depicting the ROIs drawn over where the histological samples were taken; medial (1) and lateral (2) condylar articular cartilage surface of P2 and articulating P3.

Table 1: Pulse sequence parameters for T2 mapping using the low field (0.27 T) and high field (3.0 T) MRI system

Pulse sequence	Orientation	TE (ms)	TR (ms)	FOV (mm)	Matrix	Slice width (mm)	Scan time (min)
Low field: 2D multislice multiecho spin echo	Dorsal	22, 44, 66, 88, 110	2000	210 x 210	256 x 256	3	08:00
High field: 2D multislice multi-echo spin echo	Dorsal	14, 28, 41, 55, 69	2440	140 x 140	384 x 384	3	08:15

Results

- Low field mean T2 measurements for each OARSI grade were; grade (1):99±51 (2):87±33 (3):81±19 ms and high field; (1):84±58 (2):76±44 (3):73±30 ms (Figure 3).
- Spearman's rank correlation demonstrated significant positive correlation between low and high field T2 measurements, rho 0.644 (p value <0.00002). Figure 4 shows the Bland-Altman plot and Figure 5 shows an example T2 colour map on the low and high field system.
- The intra-rater agreement for T2 measurements was excellent (ICC=0.99) and good for OARSI scores (κ=0.75)

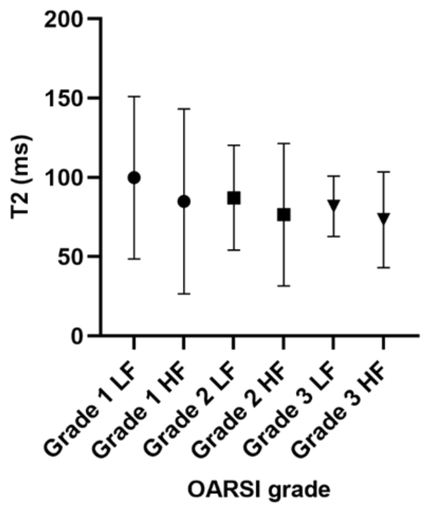

Figure 3. The mean and standard deviation of the T2 measurements for each OARSI grade measured in the low (LF) and high field (HF) MR system.

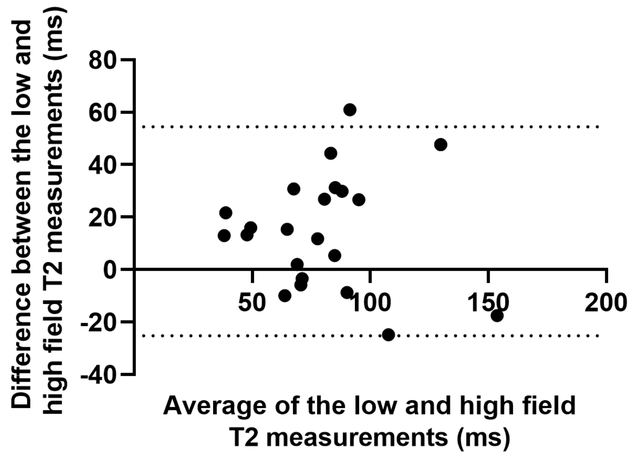

Figure 4. Bland-Altman plot showing the limits of agreement (dotted lines indicating the 95% confidence interval) between the low and high field T2 measurements.

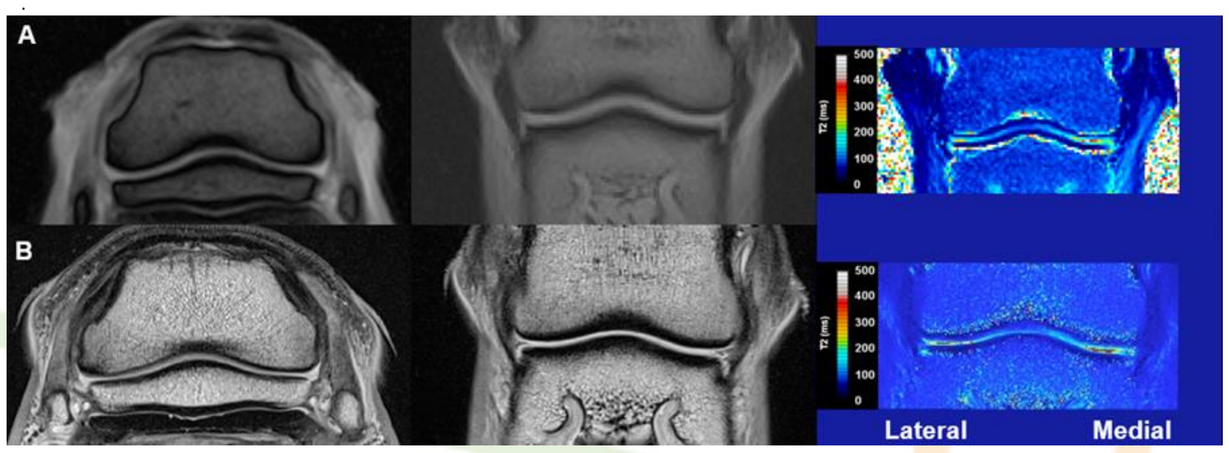

Figure 5. Right fore DIPJ imaged on both the low (A) and high (B) field MR system. Left: transverse image, centre: dorsal image and right: corresponding dorsal T2 colour map. The T2 colour map demonstrates increased T2 relaxation time in the lateral and medial articular cartilage of P2 and P3 condyles.

Discussion

There was a positive correlation between low and high field MRI demonstrating that T2 measurements on low field MRI are comparable to high field. There was not a significant difference in mean T2 relaxation time between the OARSI grades, however most histological samples had a OARSI grade 1 and there were no control samples with an OARSI grade 0 which was a limitation of this study. The findings do however suggest a higher mean T2 in pathological cartilage tissue examined in this study compared to normal equine cartilage which is reported to be 40-60 ms [3].
There are currently image resolution constraints in both systems making it difficult to measure voxels containing cartilage tissue only and so subchondral bone and synovial fluid may have been incorporated in the ROI which will impact T2 relaxation time.
The ICC value showed excellent intra-rater variability for T2 measurements and Cohen's weighted kappa showed good inter-rater variability for repeat OARSI grade measurements demonstrating robust methodology.

Conclusion

There was a positive correlation between low and high field T2 measurements and improvements in image resolution could make T2 mapping a useful quantitative diagnostic tool to measure early equine OA in the future.

References

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