Journal of Equine Veterinary Science 126 (2023) 104492

Contents lists available at ScienceDirect

Journal of Equine Veterinary Science

journal homepage: www.j-evs.com

Original Research

Assessment of Magnetic Resonance Imaging Artefacts Caused by Equine Anaesthesia Equipment: A Cadaver Study

Barbara Testa[a,b,*], Marianna Biggi[c], Christian A. Byrne[a,d], Andrew Bell[a]

[a] University of Glasgow School of Biodiversity, One Health and Veterinary Medicine, Glasgow, UK
[b] Royal (Dick) School of Veterinary Studies, University of Edinburgh, Roslin, UK
[c] Vet-CT, registered office St John's Innovation Centre, Cambridge, UK
[d] Hird & Partners Shelf Equine Hospital, Lower Giles Hill Farm, Halifax, UK

ARTICLE INFO

Article history:
Received 27 February 2023
Received in revised form 7 April 2023
Accepted 13 April 2023
Available online 16 April 2023

Keywords:
Equine
Anesthesia
Low-field MRI
Artifacts
Anesthetic equipment
Tafonius

ABSTRACT

Acquisition of magnetic resonance images of the equine limb is still sometimes conducted under general anaesthesia. Despite low-field systems allow the use of standard anaesthetic equipment, possible interferences of the extensive electronic componentry of advanced anaesthetic machines on image quality is unknown. This prospective, blinded, cadaver study investigated the effects of seven standardised conditions (Tafonius positioned as in clinical cases, Tafonius on the boundaries of the controlled area, anaesthetic monitoring only, Mallard anaesthetic machine, Bird ventilator, complete electronic silence in the room (negative control), source of electronic interference [positive control]) on image quality through the acquisition of 78 sequences using a 0.31T equine MRI scanner. Images were graded with a 4-point scoring system, where 1 denoted absence of artefacts and 4 major artefacts requiring repetition in a clinical setting. A lack of STIR fat suppression was commonly reported (16/26). Ordinal logistic regression showed no statistically significant differences in image quality between the negative control and either the non-Tafonius or the Tafonius groups ($P = 0.535$ and $P = 0.881$, respectively), and with the use of Tafonius compared to the other anaesthetic machines ($P = 0.578$). The only statistically significant differences in scores were observed between the positive control and the non-Tafonius ($P = 0.006$) and the Tafonius groups ($P = 0.017$). Our findings suggest that anaesthetic machines and monitoring do not appear to affect MRI scan quality and support the use of Tafonius during acquisition of images with a 0.31T MRI system in a clinical context.

1. Introduction

Imaging of the equine limb using MRI (magnetic resonance imaging) has proved a valuable modality as part of the investigation of lameness, providing the clinician with additional diagnostic information to allow tailored individual prognostication and treatment [1]. Advantages are particularly evident when investigating lameness that affects the equine foot, where the hoof capsule limits the diagnostic value of conventional imaging modalities [2,3]. In addition, when compared to computed tomography (CT), low-field MRI systems (LFMRI) have been shown to produce higher anatomic visualisation scores of structures like the distal sesamoidean impar ligament, synovial structures, and the distal deep flexor tendon (DDFT) [4]. Furthermore, a study comparing CT, and LFMRI showed that, despite CT allowing identification of an overall higher number of lesions in the DDFT compared to LFMRI, lesions distal to the proximal margin of the navicular bone, splits, and core lesions were identified with LFMRI only [5].

Equine MRI is commonly conducted in the standing horse to avoid the potential risks of general anaesthesia [2,6]. However, patients are sometimes anaesthetized for acquisition of images, particularly for regions proximal to the foot (more susceptible to pendulous sway motion) in order to reduce movement artefacts [1,3]. Anaesthesia of the equine patient for MRI presents multiple challenges, some of which are specifically related to this imaging modality. The use of high-field MRI systems (1.5 Tesla and above) requires a dedicated room to accommodate the MRI unit, the

Animal welfare/ethical statement: The study was approved by the Ethical Committee of the University of Glasgow School of Biodiversity, One Health and Veterinary Medicine (EA29/22).

Declaration of Competing Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

* Corresponding authors at: Barbara Testa, DVM, Royal (Dick) School of Veterinary Studies, University of Edinburgh, Roslin, UK

E-mail address: Barbara.Testa@ed.ac.uk (B. Testa).

https://doi.org/10.1016/j.jevs.2023.104492

use of MRI compatible anaesthetic equipment, and remote patient monitoring during image acquisition [7]. Furthermore, the requirements for patient positioning and limb traction during acquisition of images have been associated with post-anaesthetic complications, such as myopathies and neuropathies [8,9]. Although low-field MRI systems may offer lower image resolution for structures such as articular cartilage [1,10], they can permit more straightforward patient access and allow use of standard positioning (including surgical tables) and anaesthetic equipment [11]. Nevertheless, anaesthesia in horses involves a higher degree of morbidity and mortality [12] compared to anaesthesia in other veterinary species [13], with respiratory complications being responsible for approximately a quarter of all non-fatal complications [14].

Various advanced ventilation strategies have been proposed to reduce the effects of recumbency and anaesthesia on the equine lung while trying to minimise the cardiocirculatory effects of mechanical ventilation [15–19]. Advanced respiratory management requires complex equipment. The Tafonuis (Vetronic Services Ltd), a recently developed new generation large animal ventilator [20], delivers spontaneous and mechanical ventilation to support anaesthetized horses using a microprocessor/servo-controlled piston. This device allows the delivery of more accurate tidal volumes compared to traditional pneumatic large animal ventilators [21], independent control of inspiratory time and respiratory rate, adjustable inspired fraction of oxygen (FiO_2), adjustable continuous positive airway pressure (CPAP), and adjustable positive end-expiratory pressure (PEEP). The advanced features of the Tafonius have been successfully employed to apply CPAP [22,23], and stepwise increases in PEEP and alveolar recruitment manoeuvres to improve ventilation and oxygenation in anaesthetized horses [24] and mules [25].

However, the use of complex electronic equipment utilised in modern anaesthesia ventilators and monitors such as the Tafonius may generate electrical interference adversely affecting MRI image quality when compared to using other simpler machines (for example the Mallard medical equine anaesthesia machine or the Bird anaesthesia ventilator) with separate anaesthesia monitoring (Datex S5). Zipper artefacts, characterized by one or more spurious bands of electronic noise extending across the image, can be caused by radio waves (RF) entering the scanning room from electronic equipment during the acquisition of images.

To the best of the authors' knowledge, a rational and unbiased assessment of the effects of modern anaesthetic equipment, such as the Tafonius, on low-field MRI image quality has not been conducted. Avoiding the use of more advanced anaesthesia technology without good evidence that it is affecting MRI image quality may unnecessarily compromise outcomes in equine patients. Conversely, potential anaesthesia equipment-related artefacts may have the capacity to reduce the diagnostic yield of MRI and may significantly increase scan and anaesthesia time and any associated morbidities. Therefore, the aim of this study was to test whether the use of Tafonius consistently affected image quality through the acquisition of a series of images of the fetlock of a cadaver limb under standardised conditions. We hypothesised that, despite the extensive electronic components, the Tafonius would not generate artefacts that would affect image quality when used at a clinically useful distance from the MRI system isocentre.

2. Material and methods

2.1. Specimens and MRI unit

This prospective, blinded, cadaver study was conducted at Glasgow Equine Hospital and Practice, University of Glasgow, following approval from the Ethical Committee of the University of Glasgow School of Biodiversity, One Health and Veterinary Medicine (EA29/22).

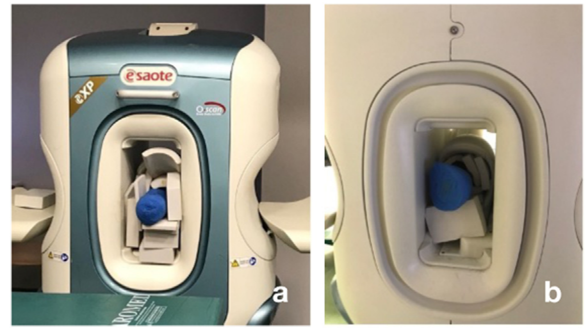

Fig. 1. Foot of an equine limb covered with a light bandage and positioned into the coil of a 0.31T Esoate O-Scan equine MRI scanner with foam positioners, patient-side (A) and operator-side (B).

Two equine cadaver forelimbs were sourced from the Undergraduate School (Vet Anatomy), University of Glasgow School of Biodiversity, One Health and Veterinary Medicine with appropriate consent for research and teaching purposes already in place. The specimens were collected soon after euthanasia and refrigerated for a maximum of 24 hours before their use.

The feet of the limbs collected were checked visually for the presence of shoes and other ferromagnetic material, and were cleaned before application of a light bandage for imaging (Fig. 1a and Fig. 1b).

As this study aimed to assess solely the presence of electronic interference-related artefacts, the only inclusion criteria were that the limbs were cut above the carpus, and of suitable size to fit into the coil of a 0.31T Esoate O-Scan equine MRI scanner (Fig. 1a). Notably, as we did not investigate any biological or pathological features of the limb itself, the limb was used as a phantom to determine the presence of interferences across the image. As such, the leg did not constitute the experimental unit in this study and the same leg could be used across multiple replicates. One limb was used for two replicates of data collection on the first study day and a second limb for the other two replicates on data collection day 2.

The controlled area, defined as the area outside which it is considered safe to place ferromagnetic objects and electronic equipment around a particular MRI scanner, with the minimum distance set at least at 0.5mT, was marked with a yellow and black tape on the floor. This area measured 198 cm from the magnet isocentre on each side on a Y axis, and 120 cm from the magnet isocentre on each side on a Z axis, leading to a distance of 232 cm from the magnet isocentre to each corner of the delimited controlled area (Fig. 2a). This latter distance was used for comparative distances between the anaesthetic machines tested and the magnet core.

2.2. Study design

Limbs were positioned into the MRI coil and stabilized by MRI-compatible foam positioners (Fig. 1a and 1b). Limbs were positioned in a manner that replicated clinical positioning at the institution, typically performed with the patient in left lateral recumbency with the limb positioned parallel to the horizontal ground surface. With the exception of the negative control (see below), the equine surgery table (Haico Telgte II, DRE Vet) and monitoring cables (electrocardiographic monitoring, pulse oximeter, and invasive blood pressure monitoring transducer) were positioned as for normal clinical cases in all the conditions tested; the surgery table was left unplugged from the power supply. All anaesthetic machines were utilized in mechanical ventilation mode, ventilating an

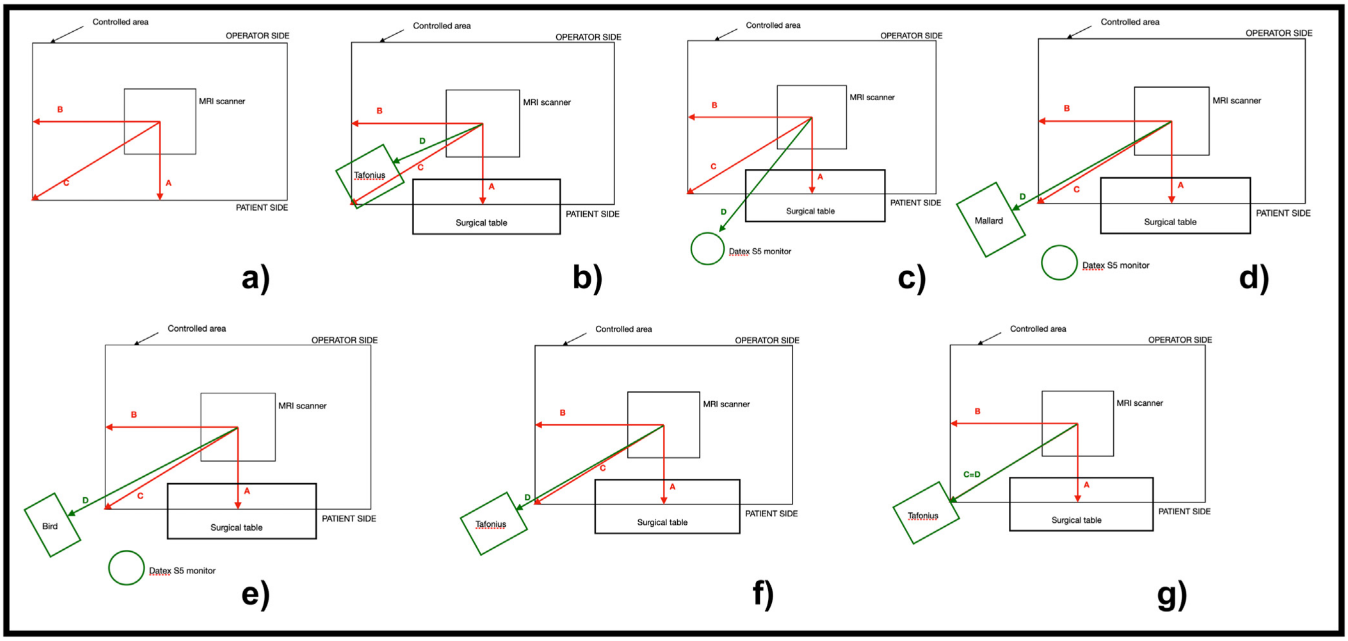

Fig. 2. Schematic representation of the setup for the seven conditions under which the MRI images were acquired. In all the conditions, distance A measures 120 cm (Z axis), distance B measures 198 cm (Y axis), distance C measures 232 cm (distance from the magnet isocentre to each corner of the controlled area); (A) negative control; (B) positive control. Distance D (front frame of the Tafonius to the magnet isocentre) measures 91 cm; (C) Datex S5 monitor only. Distance D measures 268 cm; (D) Mallard anaesthetic machine with Date S5 monitor. Distance D measures 244 cm; (E) Bird anaesthesia ventilator with Datex S5 monitor. Distance D measures 248 cm; (F) Tafonius positioned as in clinical cases. Distance D measures 243 cm; (G) Tafonius in close proximity. Distance D equals C and measures 232 cm.

Fig. 3. Set up of 6 of the seven conditions tested (the negative control is not displayed). **(A)** Positive control: MRI RF shields removed and Tafonius positioned within the controlled area; **(B)** Standard monitoring only: Datex S5 monitor on, monitoring equipment, and equine surgery table positioned as in normal clinical cases; **(C)** Mallard anaesthesia machine positioned as for standard clinical cases; **(D)** Bird anaesthesia ventilator positioned as for standard clinical cases; **(E)** Tafonius with integrated monitor on placed as for standard clinical cases; **(F)** Tafonius in close proximity (i), with detail of the front frame on the boundaries of the controlled area (ii).

equine 30L black rubber rebreathing bag (Burtons) during images acquisition.

At the beginning of each data collection day, standard localizer sequences were performed in each orthogonal plane to ensure positioning of the equine limb was subjectively comparable between the two data collection days.

Images were acquired under the following conditions (Fig. 2 and Fig. 3):

1. Negative control. Complete electronic silence in the room. No electronic equipment was present in the room, all sockets were turned off, and doors were kept closed during image acquisition (Fig. 2a).
2. Positive control. RF shields removed from machine. Source of electrical interference (Tafonius, Vetronic Services Ltd) placed within the controlled area boundaries (within which the field strength is 0.5 m Tesla or greater) (Fig. 2b and Fig. 3a). The

front frame of the Tafonius was placed at 91 cm from the magnet isocentre.

3. Standard monitoring only. Datex S5 monitor (Datex-Ohmeda S/5 compact anesthesia monitor) on and monitoring equipment (ECG, pulse oximeter probe, invasive blood pressure transducer) positioned in room as for standard clinical cases (Fig. 2c and Fig. 3b). The distance between the monitor and the MRI isocentre was 268 cm.
4. Standard machine + monitoring. Mallard anaesthesia machine (Mallard Medical Model 2800CP) positioned in room as for standard clinical cases and ventilating a rubber bag to simulate mechanical ventilation. Monitor positioned as above and turned on (Fig. 2d and Fig. 3c). The distance between the front frame of the Mallard anaesthetic machine and the MRI isocentre was 244 cm.
5. Standard machine 2. As 4 but with Bird anaesthesia ventilator (Bird Mark 7 respirator) in place of Mallard medical machine (Fig. 2e and Fig. 3d). The distance between the front frame of the Bird anaesthetic machine and the MRI isocentre was 248 cm.
6. Tafonius. Tafonius positioned normally in room as used for a clinical case. In mechanical ventilation mode with rubber bag attached and monitor on (Fig. 2f and Fig. 3e). The distance between the front frame of the Tafonius and the MRI isocentre was 243 cm.
7. Tafonius in close proximity. As 6 but with the Tafonius positioned as close to the MRI machine as the controlled area boundaries allow (Fig. 2g and Fig. 3f[i]-f[ii]). The distance between the front frame of the Tafonius and the MRI isocentre was 232 cm.

For each experimental condition, three MRI sequences of the fetlock region were acquired, replicating the routine limited fetlock MRI study used at the institution. The sequences were: transverse turbo multi echo (proton density and T2-weighted), sagittal short tau inversion recovery (STIR), sagittal turbo 3D T1 weighted. The three sequences for each of the seven experimental conditions were replicated 4 times during two separate experimental sessions. The order of the experimental conditions, the replicates, and the identifying number assigned to each condition were randomised by the primary investigator (BT). The only exception was within the positive controls, which were replicated twice at the end of all the experiments. This decision was dictated by concerns of causing damage to the equipment which would have prevented acquisition of further sequences.

Images were reviewed and scored for artefact in a blinded fashion by a board-certified veterinary radiologist experienced with the interpretation of low-field equine fetlock MRI examinations (MB). MRI studies were uploaded on and digitally transferred using PACS (picture archiving and communication system) and viewed in DICOM (digital imaging and communications in medicine) format.

The degree of artefact in each study was graded using a 4-point scale adapted from Byrne *et al* (2021) (Table 1). A free text qualitative description was also recorded for the nature of any artefact detected by the observer.

Images were graded assigning separate soft tissue and bone scores for each overall study, without differentiation of scores for individual sequences acquired within each study as a whole. Such grading was adopted as it reflects what would be done for normal clinical cases at the institution.

2.3. Statistical analysis

Scores included in the analysis were divided by scan type (soft tissue and bone) and by condition. Separate soft tissue and bone scores were used as independent outcomes. Data were analyzed using descriptive statistics in Jamovi (the Jamovi project, Sydney, Australia) and presented as median and range in box and whisker plots. To further investigate whether the choice of machine influenced scan quality, we used ordinal outcomes logistic regression in Jamovi. Conditions were grouped into negative, positive, Tafonius (which encompassed Tafonius as used in normal clinical cases and Tafonius in close proximity), and non-Tafonius (which encompassed monitoring only, Bird, and Mallard) groups and included in the model as the independent variable, while the dependent variable was represented by the grade assigned to each study. Model strength was evaluated using the Akaike Information Criterion (AIC) and McFadden's R^2. The level of significance was set at $P < 0.05$.

3. Results

A total of 78 sequences were acquired from 26 complete MRI studies (four replicates for six of the seven conditions and two replicates for the positive control group). Data analyzed by MRI study type therefore generated 52 scores used for analysis, with eight scores for six out seven conditions and four scores for the positive controls.

Qualitatively, all images displayed some degree of loss of definition of the palmar soft tissue both at the proximal and distal edge of the scanned area. The distinction between trabecular and cortical / subcondral bone was very good in all images. The definition of soft tissue was very similar between studies other than the positive controls, and difference between grade 1 and 2 was deemed minimal. Overall, eight replicates were scored 1 (two Bird, two Tafonius in close proximity, one Tafonius as in normal clinical cases, one negative, one monitoring only, and one Mallard).

The two positive controls were associated with background noise and poor signal-to-noise ratio, which would have required repetition of scans in a clinical setting. In particular, one of the two positive controls would have required repetition of the transverse turbo multi echo (proton density and T2-weighted) sequence, while the other positive control repetition of all the sequences. In the other conditions, the artefact detected in images graded 2 or higher was lack of STIR fat suppression (16/26). Examples of sagittal T1 sequences of each grade are shown in Fig. 4.

Table 1
Scoring system for the presence of artefacts with the use of *Esaote* 0.31T *O scan*. Adapted from Byrne *et al* 2021.

Grade	Summary	Grading qualifiers
1	Excellent quality	The study is characterized by optimal tissue definition with no artefacts detected. Images in the study are of ideal quality*. The study would not be repeated in a routine clinical context
2	High diagnostic quality	Mild loss of tissue definition with presence of artefacts that do not limit interpretation. The study would not be repeated in a routine clinical context
3	Satisfactory diagnostic quality	Moderate loss of tissue definition with presence of artefacts that do not limit interpretation. The study would not be repeated in a routine clinical context
4	Non-diagnostic	Presence of artefacts severely affects the study and prevents assessment of significant structures. The study would be repeated in a routine clinical context

* Ideal quality refers to the highest quality achievable with a low-field (0.3T) system, as the one utilised in this study

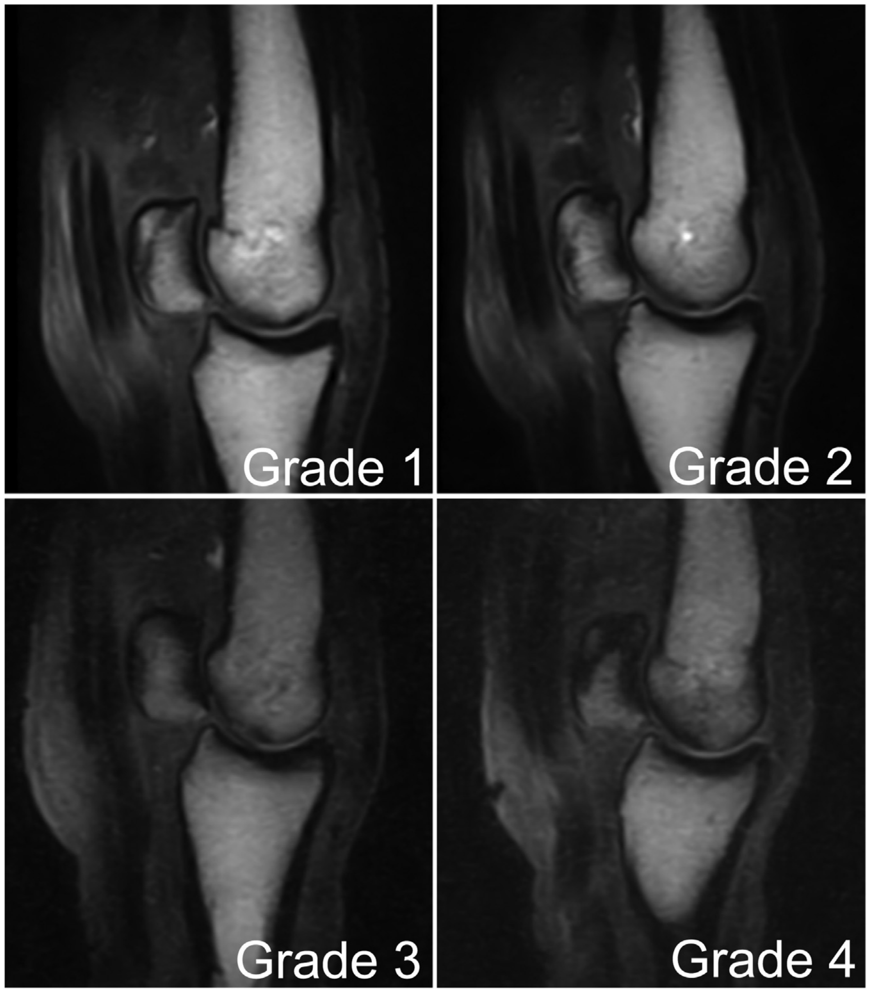

Fig. 4. Sagittal turbo 3D T1 weighted magnetic resonance images of the fetlock of an equine cadaver limb showing differences in image quality as graded according to the scoring system utilized in our study.

Table 2
Descriptive statistics of the scores generated for all the conditions tested.

	ID	n	Missing	Median	Minimum	Maximum
Grade	Bird	8	0	1.50	1	2
	Datex only	8	0	2.00	1	3
	Mallard	8	0	1.50	1	2
	Negative	8	0	2.00	1	2
	Positive	4	0	2.50	2	4
	Tafonius close proximity	8	0	2.00	1	3
	Tafonius normal	8	0	2.00	1	3

ID: identification of seven different setups (conditions) tested; N: number of scores available for each setup.

As shown in Table 2, scan quality was good in all groups and comparable to the negative control with only the positive control group requiring repeats due to major artefacts (grade 4).

Figure 5 provides a graphic representation of the distribution of scores in the seven conditions tested, which were then grouped into positive, negative, Tafonius and non-Tafonius groups as shown in Figure 6.

The grouped conditions were included into an ordinal logistic regression model to investigated whether scores significantly differed between the Tafonius and non-Tafonius groups (Table 3). No statistically significant differences in image quality were detected between the negative control and the non-Tafonius group ($P = 0.535$), as well as with the use of Tafonius compared to other large animal anaesthetic machines ($P = 0.578$). The only statistically significant difference in scores was observed between the positive control and the non-Tafonius group reference ($P = 0.006$).

Similarly, when the grouped conditions were included into the ordinal logistic regression model utilizing the Tafonius group as reference, the only statistically significant difference in scores was observed between the positive control and the Tafonius group ($P = 0.017$) (Table 3).

4. Discussion

We acquired a series of images of the fetlock of two equine cadaver limbs to investigate the impact of large animal anaesthetic types of equipment on image quality using a low-field MRI system. Results of the present study showed no significant effect of

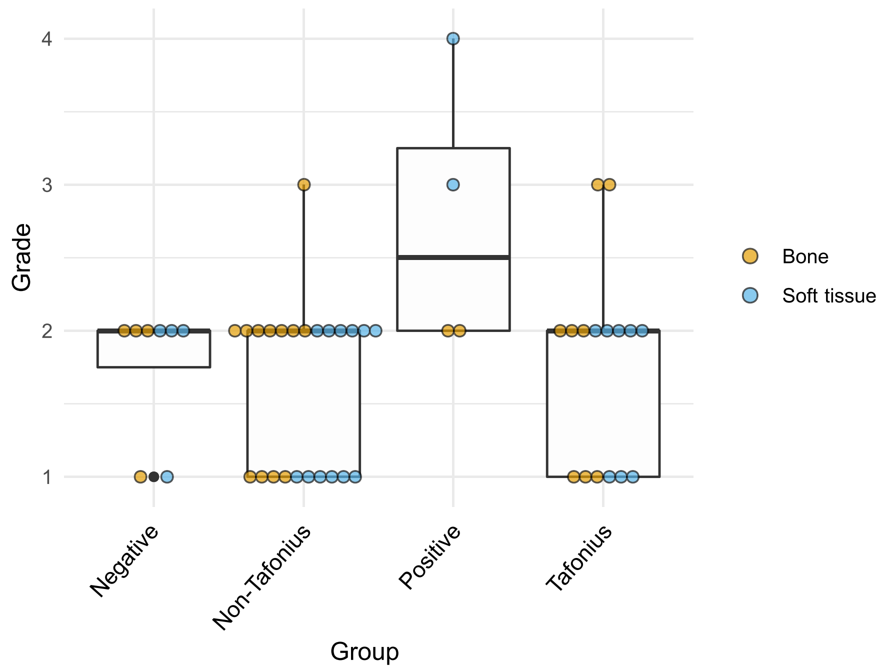

Fig. 5. Box plot of the distribution of scores split by soft tissue and bone scan type in the seven conditions tested. The box represents the 25th-75th quartile (interquartile range), the horizontal line within the box represents the median, the vertical lines (whiskers) represent the minimum and maximum value, and outliers are shown as dots beyond the whiskers.

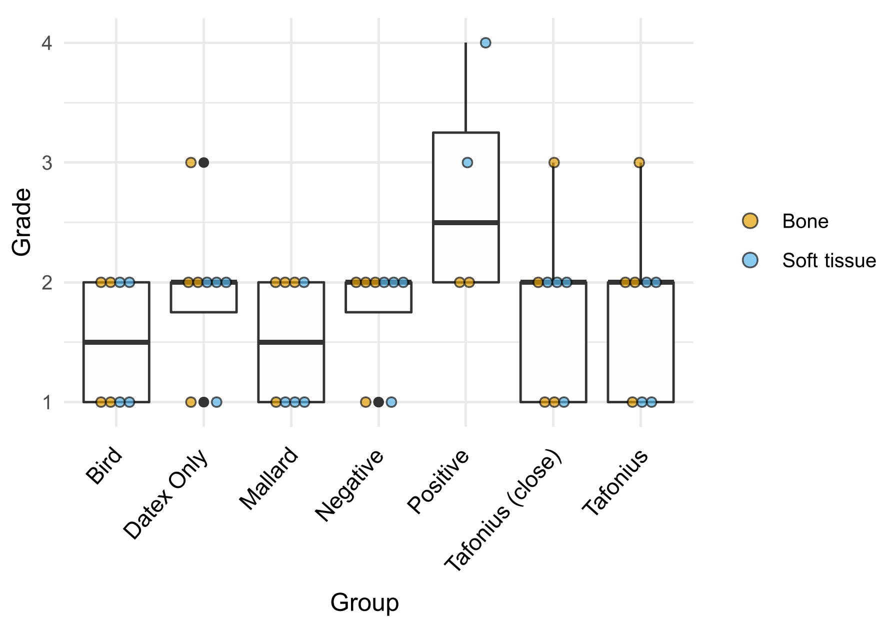

Fig. 6. Box plot of the distribution of scores split by soft tissue and bone scan type in the conditions tested grouped as positive, negative, Tafonius, and non-Tafonius groups. The box represents the 25th-75th quartile (interquartile range), the horizontal line within the box represents the median, the vertical lines (whiskers) represent the minimum and maximum value, and outliers are shown as dots beyond the whiskers.

Table 3
Results of ordinal logistic regression to investigate whether there was a statistically significant difference between scores in groups when compared to non-Tafonius and to the Tafonius groups.

Predictor	Reference	Estimate	SE	Z	*P*
Grouped					
Negative	Non-Tafonius	0.493	0.796	0.620	.535
Positive	Non-Tafonius	3.295	1.200	2.745	.006
Tafonius	Non-Tafonius	0.364	0.653	0.557	.578
Positive	Tafonius	2.929	1.225	2.390	.017
Negative	Tafonius	0.129	0.857	0.150	.881

The McFaddens R^2 and AIC for the model were 0.078 and 105, respectively.

the anaesthetic equipment used on image quality. In particular, our findings support the research hypothesis, suggesting that Tafonius, when used at a clinically useful distance from the MRI system isocentre, does not appear to generate clinically significant artefacts that affect image quality. Also, on the basis of the positive control, the internal shielding of the system seemed to prove effective in protecting against major interferences.

The vast majority of the MRI studies acquired were of satisfactory to excellent quality (grades 1, 2, and 3), with no significant differences between groups and when compared to the negative control. Our results therefore show that various large animal anaesthetic machines, when used appropriately, do not significantly interfere with image quality when using a 0.3T low-field MRI system with internal shielding such the one utilized in this study. This is consistent with previous published veterinary literature [26], where the signal-to-noise ratio and the presence of artefacts were investigated in relation to the use of an equine surgery table and anaesthetic equipment utilizing an open bore 0.2T magnet with no internal shielding. As in our study, also this work demonstrated no statistically significant effect of anaesthetic equipment on MRI image quality. Contrary to the findings of the current study, the same work [26] observed a significant negative effect of anaesthetic monitoring. This highlights that the findings of the current study are applicable to the Esoate O-scan MRI system but may not directly apply to different low-field MRI acquisition systems (with different shielding properties). A particular consideration pertains to the distance between any potential source of electronic interference and the MRI isocentre: the demarcated controlled area at our institution is broader compared to the minimum safety distances from the MRI isocentre advised by the manufacturer. This implies that all our anaesthetic monitoring equipment, including monitoring cables (all positioned outside or on the boundaries of the controlled area) sat at a greater distance compared to that normally considered safe for electronic equipment and ferromagnetic material. Furthermore, the previous study was conducted in live patients, while we used fresh, refrigerated cadaver limbs.

To the best of the authors' knowledge, this is the first study specifically testing the possible interference caused by the extensive electronic components of Tafonius on MR images. In order to improve ventilation and oxygenation in anaesthetized equine patients, this state-of-the-art anaesthetic equipment enables the anaesthetist to apply advanced ventilatory strategies when required. Previous studies have demonstrated that the degree of alveolar collapse can be reduced by application of an alveolar recruitment manoeuvre (ARM) and continuous PEEP [16,27,28]. An alternative approach consists of an ARM provided by stepwise incremental and decremental peak inspiratory pressure (PIP) and PEEP, which has been found to be amongst the most effective methods to redistribute ventilation and improve oxygenation [29,30]. Additional strategies involve the use of continuous CPAP, which also proved effective in redistributing ventilation to the dependent lung regions, thereby decreasing ventilation/perfusion mismatch [23]. Tafonius allows the delivery and accurate titration of all the above-mentioned strategies, with the ultimate goal of improving patients' outcome. Results of our study showed no evidence that Tafonius causes poorer scan quality compared to images acquired with the other anaesthetic machines tested, hence supporting its use in a clinical context also in patients anaesthetized for MRI procedures.

In the present study, only the positive controls were graded as nondiagnostic and would have been repeated in a clinical context. The presence of true positive controls is reassuring in terms of validation of our findings.

However, we observed a certain degree of variability in image quality between replications, notably also amongst the positive and negative control groups. In fact, not all the positive control sequences demonstrated the same degree of artefacts, although they were conducted in similar conditions. Likewise, the negative controls failed to display the best image quality amongst all the other setups. This variability did not seem to be directly related to the anaesthetic equipment used. Additional methodological factors and sources of variability might explain variations in grading detected in our study and the lack of fat suppression as the artefact detected.

Fluctuations in environmental temperature can affect the homogeneity of the magnetic field, impacting the quality of images and consistency between scans, while the temperature of tissues can alter suppression of the fat signal [31].

Ambient temperature was kept as constant as possible in the MRI room at our institution, although minor fluctuations cannot be ruled out, and temperature was not specifically recorded in the present study.

The use of equine cadaver limbs may be associated with altered tissue contrast between structures compared to the live patient. This might have affected image quality due to tissue autolysis [32] thus leading to overall inferior image quality compared to live patients [33]. However, recent equine research in advanced imaging techniques on the fetlock of Thoroughbred racehorses using a LFMRI system has demonstrated that diagnostic quality of MR images doesn't significantly differ between live, fresh cadaver, and frozen/thawed tissues [32]. Moreover, the use of cadaver limbs in equine MRI studies has been widely adopted by multiple other authors and has demonstrated high diagnostic value to investigate the pathology of the equine distal limb [34–39].

STIR sequences are particularly affected by tissue temperature, and fat signal might not be sufficiently suppressed unless the inversion time is adjusted [31]. In our study, STIR sequences were acquired following the usual clinical protocol, with no adjustments of the TE (echo time) to accommodate the lower temperature of cadaver limbs. While this might explain why lack of suppression was frequently detected, it is worth mentioning that the same protocol was consistently applied to all scans, and approximately 40% showed adequate fat suppression. It is therefore unlikely for this aspect to account for all of the variation observed.

Study planning by the operator and positioning of the area of interest at the magnet isocenter are crucial steps to optimize image quality [31]. During the research presented here, accurate and reproducible positioning of the limb as in normal clinical cases was performed by an experienced veterinary surgeon (CB) in both experimental sessions, with the fetlock placed at the MRI isocenter. As shown by our results, loss of definition was observed solely at the distal edges of the image, where the magnetic field homogeneity is lower compared to the center of the field of view. Furthermore, while the use of multiple observers might have strengthened our findings, we believe the use of a single operator (BT) to run all the sequences minimized the variability associated with study planning.

Other electrical activity in the room or in the adjacent rooms might have affected the homogeneity of the magnetic field, introducing a source of variability. We ensured that electrical silence was present in the room during images acquisition, and all doors leading to the MRI suite were kept close at all times. We could not control activities (which also encompassed the use of electronic equipment) in adjacent rooms, and although this might explain part of the variability we observed in our studies, no zipper artefacts were detected in any of our images.

Finally, regular servicing of the machine, for example shimming, is important to optimize the magnet homogeneity [31]. During the present project, all the sequences were acquired in close succession, hence this aspect should be relatively consistent across the study.

Overall, the considerations elucidated above can account for relatively minor variations (especially within grade 1 and 2) which we believe would have limited relevance in a clinical context.

There are a number of limitations in our study to acknowledge. Firstly, we acknowledge the relatively low sample size, especially for the positive controls. As this represents pilot work, an *a priori* sample size calculation could not be performed. However, considering that we endeavoured to keep confounding variables constant and that the focus was solely on the presence of artefacts, we feel a higher number of scans would be unlikely to yield different results. This preliminary study will be valuable to inform prospective clinical studies using non-cadaver limbs. Secondly, only one radiologist reviewed and scored the scans. Nonetheless, scoring was performed by a specialist veterinary radiologist with extensive experience specifically in equine imaging, who was unaware of group assignment. The presence of artefacts was also graded utilizing a subjective scoring system adapted from a previously published scoring system [3], and detailed definitions were provided for each grade. Thirdly, some other factors possibly affecting scan quality were not fully controlled or recorded, such as temperature and activity in adjacent rooms. We suspect all these factors were responsible for only minor, non-clinically significant variations, and they might explain the baseline variability observed in our study.

5. Conclusions

Our results suggest that MRI scan quality is not affected by anaesthetic equipment when this is used at the recommended distances from the MRI isocenter. In particular, there is no clear evidence that the extensive electronic components of the Tafonius are responsible for clinically relevant artefacts. Based on our results, use of Tafonius is suitable during acquisition of images with a 0.31T MRI system equipped with internal shieling in a clinical context.

Financial disclosure

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Barbara Testa: Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Data curation, Visualization, Project administration. **Marianna Biggi:** Investigation, Writing – review & editing. **Christian A. Byrne:** Conceptualization, Investigation, Writing – review & editing. **Andrew Bell:** Conceptualization, Methodology, Formal analysis, Data curation, Writing – review & editing, Project administration, Supervision.

Acknowledgments

We would like to thank Susan Glattbach and Sam Johnstone from the Undergraduate School (Vet Anatomy), University of Glasgow School of Biodiversity, One Health and Veterinary Medicine for their help in sourcing the specimens.

References

[1] Barrett MF, Frisbie DD, King MR, Werpy NM, Kawcak CE. A review of how magnetic resonance imaging can aid in case management of common pathological conditions of the equine foot. Equine Vet Educ 2017;29(12):683–93.
[2] Bolen G, Audigié F, Spriet M, Vandenberghe F, Busoni V. Qualitative comparison of 0.27T, 1.5T, and 3T magnetic resonance images of the normal equine foot. J Equine Vet Res 2010;30(1):9–20.
[3] Byrne CA, Marshall JF, Voute LC. Clinical magnetic resonance image quality of the equine foot is significantly influenced by acquisition system. Equine Vet J 2021;53:469–80.
[4] Vallance SA, Bell RJW, Spriet M, Kass PH, Puchalski M. Comparison of computed tomography, contrast-enhanced computed tomography and standing low-field magnetic resonance imaging in horses with lameness localised to the foot. Part 1: Anatomic visualisation scores. EVJ 2012;44:51–6.
[5] Vallance SA, Bell RJW, Spriet M, Kass PH, Puchalski M. Comparison of computed tomography, contrast-enhanced computed tomography and standing low-field magnetic resonance imaging in horses with lameness localised to the foot. Part 2: Lesion identification. EVJ 2012;44:149–56.
[6] Porter EG, Werpy NM. New concepts in standing advanced diagnostic equine imaging. Vet Clin Equine 2014;30:239–58.
[7] Murray R. Chapter 2. High-field MRI in horses: practicalities and image acquisition. 2A: Practicalities and image acquisition. In: Murray RC, editor. Equine MRI. Chichester, UK: John Wiley & Sons Ltd p; 2010. p. 39–49.
[8] Franci P, Leece EA, Brearley JC. Post anaesthetic myopathy/neuropathy in horses undergoing magnetic resonance imaging compared to horses undergoing surgery. Equine Vet J 2006;38(6):497–501.
[9] Moreno KL, Scallan EM, Friedeck WO, Simon T. Transient pelvic limb neuropathy following proximal metatarsal and tarsal magnetic resonance imaging in seven horses. EVJ 2020;52:359–63.
[10] Murray RC, Mair TS, Sherlock CE, Blunden AS. Comparison of high-field and low-field magnetic resonance images of cadaver limbs of horses. Vet Rec 2009;165:281–8.
[11] Leece E. Chapter 2. High-field MRI in horses: practicalities and image acquisition. 2B: General anaesthesia for MRI. In: Murray RC, editor. Equine MRI. Chichester, UK: John Wiley & Sons Ltd p; 2010. p. 51–61.
[12] Johnston GM, Eastment J, Wood J, Taylor P. The confidential enquiry into perioperative equine fatalities (CEPEF): mortality results of Phases 1 and 2. Vet Anaesth Analg 2002;29:159–70.
[13] Brodbelt DC, Blissitt KJ, Hammond RA, Neath PJ, Young LE, Pfeiffer DU, et al. The risk of death: the confidential enquiry into perioperative small animal fatalities. Vet Anaesth Analg 2008;35:365–73.
[14] Laurenza C, Ansart L, Portier K. Risk factors of anaesthesia-related mortality and morbidity in one equine hospital: a retrospective study on 1,161 cases undergoing elective or emergency surgeries. Front Vet Sci 2020;6 article 514.
[15] Hubbell JAE. Review of support of ventilation in the anesthetized horse. AAEP Proceedings 2010;56:33–7.
[16] Hopster K, Kästner SBR, Rohn K, Ohnesorge B. Intermittent positive pressure ventilation with constant positive end-expiratory pressure and alveolar recruitment manoeuvre during inhalation anaesthesia in horses undergoing surgery for colic, and its influence on the early recovery period. VAA 2011;38:169–77.
[17] Ambrosio AM, Kelia KI, Souto MTMR, Oshiro AH, Fantoni DT. Effects of positive end-expiratory pressure titration on gas exchange, respiratory mechanics and hemodynamics in anesthetized horses. VAA 2013;40:564–72.
[18] Auckburally A, Nyman G. Review of hypoxaemia in anaesthetized horses: predisposing factors, consequences and management. VAA 2017;44:397–408.
[19] Mosing M, Senior JM. Maintenance of equine anaesthesia over the last 50 years: controlled inhalation of volatile anaesthetics and pulmonary ventilation. Equine Vet J 2018;50:282–91.
[20] Moens YP, Hallowell WS, Schramel JP. A new generation of large animal ventilators. Pferdeheilkunde 2016;32(5):443–8.
[21] Floriano D, Hopster K, Driessen B. Accuracy of tidal volume delivery by five different models of large-animal ventilators. AJVR 2020;81(11):857–64.
[22] Mosing M, MacFarlane P, Bardell D, Lüthi L, Cripps PJ, Bettschart-Wolfensberger R. Continuous positive airway pressure (CPAP) decreases pulmonary shunt in anaesthetized horses. VAA 2016;43:611–22.
[23] Mosing M, Auer U, MacFarlane P, Bardell D, Schramel JP, Böhm SH, Bettschart–Wolfensberger R, Waldmann AD. Regional ventilation distribution and dead space in anaesthetized horses treated with and without continuous positive airway pressure: novel insights by electrical impedance tomography and volumetric capnography. VAA 2018;45:31–40.
[24] Hopster K, Duffee LR, Hopster-Iversen CCS, Driessen B. Efficacy of an alveolar recruitment maneuver for improving gas exchange and pulmonary mechanics in anesthetized horses ventilated with oxygen or a helium-oxygen mixture. AJVR 2018;79(10):1021–7.
[25] Hoeberg E, Levionnois O, Andréïs S. Successful management of hhypoxaemia in a mule during general anaesthesia. Vet Rec Case Reports 2021;9:e104.
[26] Tapprest J, Audigié F, Radier C, et al. Application of magnetic resonance imaging to the horse: influence of external factors on image quality at low field. Rev Med Vet 2003;154(8):515–20.
[27] Hubbell JAE, Muir WW. Oxygenation, oxygen delivery and anaesthesia in the horse. EVJ 2015;47:25–35.
[28] Andrade SRM F, Facó LL, Ida KKI, Silva CLC L, Fantoni DT, Ambrosio AM. Effects of 12 and 17 cmH2O positive end-expiratory pressure applied after alveolar recruitment maneuver on pulmonary gas exchange and compliance in isoflurane-anesthetized horses. VAA 2019;46:64–73.
[29] Küls N, Braun C, Moens Y. The use of positive end-expiratory pressure (PEEP) and alveolar recruitment manoeuvre (ARM) in equine anaesthesia – a review. Pferdeheilkunde 2016;32(5):436–42.
[30] Andrade SRM F, Ambrosio AM, Rodrigues RR, Facó LL, Gonçalves LA, Filho GGS, et al. The optimal PEEP after alveolar recruitment maneuver assessed by electrical impedance tomography in healthy horses. Front Vet Sci 2022;9:1024088.
[31] Murray R, Werpy N. Chapter 4. Image interpretation and artefacts. In: Murray RC, editor. Equine MRI. Chichester, UK: John Wiley & Sons Ltd; 2010. p. 101–45.
[32] Johnston GCA, Ahern BJA, Woldeyohannes SM, Young AC. Does the low-field MRI appearance of intraosseous STIR hyperintensity in equine cadaver limbs change when subjected to a freeze-thaw process? Animals 2021;11:475.
[33] Röttiger C, Hellige M, Ohnesorge B, Bienert-Zeit A. Magnetic resonance imaging and computed tomography of equine cheek teeth and adjacent structures: comparative study of image quality in horses in vivo, post-mortem and frozen-thawed. Acta Vet Scand 2019;61:62.
[34] Olive J, D'Anjou MA, Girad C, Laverty S, Theoret C. Fat-suppressed spoiled gradient-recalled imaging of equine metacarpophalangeal articular cartilage. Vet Radiol Ultrasound 2010;51(2):107–15.
[35] Olive J, D'Anjou MA, Alexander K, Laverty S, Theoret C. Comparison of magnetic resonance imaging, computed tomography, and radiography for assessment of noncartilaginous changes in equine metacarpophalangeal osteoarthritis. Vet Radiol Ultrasound 2010;51(3):267–79.

[36] Smith MA, Dyson SJ, Murray RC. The appearance of the equine metacarpophalangeal region on high-field vs. standing low-field magnetic resonance imaging. Vet Radiol Ultrasound 2011;52(1):61–70.
[37] O'Brien T, Baker TA, Brounts SH, Sample SJ, Markel MD, Scollay MC, Marquis P, Muir P. Detection of articular pathology of the distal aspect of the third metacarpal bone in thoroughbred racehorses: comparison of radiography, computed tomography and magnetic resonance imaging. Vet Surg 2011;40:942–51.
[38] Werpy NM, Ho CP, Pease AP, Kawcak CE. The effect of sequence selection and field strength on detection of osteochondral defects in the metacarpophalangeal joint. Vet Radiol Ultrasound 2011;52(2):154–60.
[39] Carstens A, Kirberger RM, Dahlberg LE, Prosezky L, Fletcher L, Lammentausta E. Validation of delayed gadolinium-enhanced magnetic resonance imaging of cartilage and T2 mapping for quantifying distal metacarpus/metatarsus cartilage thickness in thoroughbred racehorses. Vet Radiol Ultrasound 2013;54(2):139–48.