Science-in-brief: Risk assessment for reducing injuries of the fetlock bones in Thoroughbred racehorses

In March 2020, a symposium was held in Newmarket, UK, aiming to discuss measures which could be used internationally to reduce the risk of catastrophic fracture associated with the fetlock joint. The meeting was supported by the Gerald Leigh Charitable Trust, the Beaufort Cottage Charitable Trust and the Jockey Club with additional contributions from a number of industry stakeholders (Data S2). On the first day a panel of international experts (Data S1: The FRAT Group) discussed risk assessment protocols, particularly those based on imaging features which might indicate increased risk of imminent fracture. This was followed by a wider discussion with a diverse invited audience (Data S3), on how our current knowledge of fracture pathophysiology and risk factors for injury could be used to target risk assessment protocols. A delegates’ survey on the key discussion points allowed quantification of opinions. This editorial highlights key meeting outcomes and identifies actionable items that can be taken forward with immediate effect.

1 | THE IMPORTANCE OF RISK REDUCTION

With the ethics of the racing industry now in the public spotlight, there is recognition that together veterinary and horseracing professionals must strive to realise an improvement in equine injury rates. Indeed the USA Thoroughbred Safety Coalition Survey in 2019 identified that the public entrusts racehorse welfare to the veterinary profession and 74.1% of meeting participants strongly agreed that improving injury risk assessment is an important veterinary contribution to racehorse welfare. Intervention through risk profiling programmes, primarily based on training and racing metrics, has a proven track record. The success of a Racing Risk Management Program in New York gives evidence that intervention is successful.2

In general, development of fatigue injury to the joint surface and underlying subchondral bone of the fetlock joint is a consequence of the high loads inherent in current Thoroughbred training and racing practices.3-5 Although often resulting in a mild, multi-limb lameness, many racehorses are able to continue to train and race successfully with fetlock fatigue injury. Studies suggest that catastrophic musculoskeletal injuries are a rare event at the race start level.6-11 However, reliance solely on race start data is flawed as it fails to capture prevalence of injuries sustained in training. Furthermore, although uncommon, the cost to the individual horse is high as catastrophic musculoskeletal injuries are fatal and individual risk is increased by multiple starts over a racing career. Fetlock fatigue damage may affect optimal athletic performance, lead to early retirement due to reduced performance, limit a horse’s future career in other pursuits or increase risk of serious injury during a race.4

2 | PROFILING TO INFORM RISK ASSESSMENT

Risk profiling examines the nature and levels of threat faced by an individual and seeks to define the likelihood of adverse events occurring. Catastrophic fracture is usually the end result of repetitive loading and currently there are no techniques that can accurately determine the number of load cycles a bone can sustain prior to failure in individual cases. Techniques based on evaluation of structure require further investigation to identify how certain architectural features of bone alter the risk of future injury. However, diagnostic imaging has clear potential to provide information about the prodromal pathology that has been commonly observed in association with fracture at post-mortem.12-16 Previous published work has identified a plethora of epidemiological factors associated with increased risk of serious catastrophic musculoskeletal injury on the racetrack. A recent meta-analysis study10 distilled these into race, horse and management related risk factors that could be combined in statistical models to enable identification of individual horses that may be at increased risk of injury. For these high-risk horses further imaging investigations may then be appropriate.

The problem with all statistical models created so far is that they have a poor positive predictive ability due to the actual low prevalence of racetrack catastrophic events. Indeed a model created by Georgopoulos and Parkin,17 based on data from over 2 million race starts and almost 4 million workout starts, suggested that if we had to choose between two horses starting in a race their model would only correctly identify the horse about to sustain a fracture 65% of the time. This is barely higher than the 50% you could achieve with the toss of a coin. Additionally, given the fact that both positive and negative predictive values are strongly influenced by prevalence, the
low prevalence of catastrophic injury means it will always be difficult to predict regardless of which diagnostic procedure is employed. One possible strategy to overcome this inherent challenge involves serial testing (Figure 1) to refine subpopulations of interest and improve the predictive ability of specific tests applied in sequence.

Racing at racetracks and/or exposure to training practices to which horses are not habituated may potentially increase risk of serious injury and targeted investigation and location-specific interpretation of imaging findings may be justifiable. With any and all tests having the potential for misdiagnosis, risk profiling will not be without associated costs and these need to be considered. An additional complication is the conflicting evidence on how to interpret the findings at pre-race, individual horse clinical appraisal. Indeed, 90% of horses that experienced a fatal injury at the Hong Kong Jockey Club showed no detectable clinical signs at pre-race veterinary inspection. The same authors retrospectively examined a large dataset of pre-race inspections based on physical examination in which horses were assigned to one of three groups based on clinical findings (pass, marginal pass and fail). It was estimated that to prevent one fatal injury in the group of horses with ‘marginal’ passes, 200 additional horses would have to be withdrawn from races. Withdrawal of such a large number to prevent a single case of injury would have a profound and far reaching impact on the racing industry to which there is no immediate solution. Indeed, in the post-meeting survey the delegates remained divided over whether it is possible to define what level of risk is acceptable and how many horses it would be appropriate to withdraw from a race to save a single animal.

3 | Diagnostic Techniques for Fetlock Injury Risk Profiling

Currently there is no clear consensus to support definitive criteria for interpretation of images from all modalities and important areas of uncertainty exist. This is linked to the fact that although a range of imaging modalities are available, each with their own strengths and weaknesses (Table 1), advances in technology currently outstrip our accumulation of published evidence on which to base interpretation of the images obtained. Furthermore, injury development and recovery are dynamic processes with features that can be difficult to distinguish.

Interpretation is easy when the imaging modality shows an unequivocal fracture; determined by the FRAT group as a radiolucent line (radiography/CT) or a linear defect with associated fluid signal (MRI) that breaches the subchondral bone plate or the cortex of the bone. Here the decision is simple: the horse has a fracture and must stop exercising. Many cases, however, will demonstrate less clearly defined changes with bone fatigue injury. Here, more longitudinal imaging studies are vital to understand the relevance of specific imaging features and risk of progression of this pathologic process to serious injury. It is also acknowledged that significant pre-fracture pathology may develop in the absence of any detectable, clinical signs in some horses. Given this general background, the findings revealed by each imaging modality are explored below.

Currently radiography remains the most important imaging modality in fetlock bone risk assessment. With wide availability and the knowledge gained by more advanced imaging techniques refining the most appropriate projections to use; radiography represents a relatively untapped resource that through education of primary care vets could immediately have a profound impact on injury mitigation. Indeed, in a study on the effect of intrasynovial medication on fracture risk, targeted imaging was only carried out before medication in 7.3% of cases. This starkly demonstrates the currently low levels of application in some geographical areas and indicates how education to enhance clinical monitoring and basic radiography is likely to reduce both racehorse population attrition and individual losses. The most suitable projection with which to detect prodromal condylar...
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<tr>
<td>Radiography</td>
<td>Widely available. Rapid image acquisition times and can be performed un-sedated in most horses.</td>
<td>Has the potential to detect radiolucent lines indicative of stress fracture or areas of radiolucency suggestive of bone resorption and prodromal fracture pathology.</td>
<td>2D data leading to superimposition of structures. Variability in beam angle and technique may modify the image. Interpretation fairly subjective, particularly with subtle findings.</td>
<td>Sensitivity of each projection for detection of condylar fracture/fissure currently untested. Interobserver agreement in interpretation of the same images not defined.</td>
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<tr>
<td>Nuclear scintigraphy</td>
<td>Large areas can be easily imaged. Intermediate image acquisition times.</td>
<td>Functional imaging technique able to identify areas of increased bone turnover. Useful for localising abnormalities to a specific area.</td>
<td>2D data with superimposition and low spatial resolution. Provides limited detail about specific lesion types. Requires temporary isolation of the horse in line with radioactivity safety guidelines which disrupts the training programme close to a race. Requires sedation which limits use close to a race due to drug withdrawal times.</td>
<td>Low specificity; more work needed to understand the significance of increased bone turnover in all anatomical locations. Interobserver agreement in interpretation of the same images not defined</td>
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<tr>
<td>Computed tomography (CT)</td>
<td>3D data with high spatial resolution. Rapid image acquisition times.</td>
<td>Optimal method for detection of structural changes in bone. Best sensitivity to detect abnormalities in shape or density of bone. Able to identify: -cracks -areas of increased bone density (sclerosis) -areas of decreased bone density (resorption).</td>
<td>Unable to provide functional information. Requires sedation which limits use close to a race due to drug withdrawal times.</td>
<td>With current knowledge limited ability to distinguish between active abnormalities and static, chronic changes. Limited knowledge of the relative risk of propagation to more serious injury, of all structural features that can be identified with this modality. Third generation dual-energy scanners may allow the detection of bone marrow oedema in the future. Requires further validation and elucidation of sensitivity and specificity for detection of different lesions. Interobserver agreement in interpretation of the same images not defined.</td>
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<tr>
<td>Magnetic resonance imaging (MRI)</td>
<td>3D data. Only solo modality to combine structural and biochemical information.</td>
<td>Provides some information on the physiological metrics and activity associated with lesions. Provides a combination of structural information from PD and T1-weighted sequences and some functional information from T2-weighted and STIR, fluid sensitive, sequences. Currently limited ability to detect subtle bone changes with the standing, low-field system due to limited spatial resolution.</td>
<td>Limited spatial resolution inherent to the low magnetic field and motion experienced whilst imaging a standing horse. Variability in image quality between different system sites. Requires sedation which limits use close to a race due to drug withdrawal times.</td>
<td>Condylar fluid patterns need to be validated with respect to chronicity of injury and risk of fracture propagation. Requires further validation and elucidation of sensitivity and specificity for detection of different lesions. Interobserver agreement in interpretation of the same images not defined.</td>
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<td>Positron emission tomography (PET)</td>
<td>3D data with moderate spatial resolution. Possibility of quantification of increased bone turnover in different areas. Short half-life of the radioactive isotope makes it suitable for use at the racetrack with minimal disruption to training.</td>
<td>Best imaging modality for functional assessment of bone. Most sensitive technique for detection of early bone changes as it provides functional information at the molecular level, prior to occurrence of structural changes. Active and inactive abnormalities can be distinguished when combined with a structural imaging technique such as CT or MRI.</td>
<td>Requires association with a structural imaging technique to allow full assessment and complete description of an abnormality. Requires sedation which limits use close to a race due to drug withdrawal times.</td>
<td>New modality that requires further validation and elucidation of sensitivity and specificity for detection of different lesions. Interobserver agreement in interpretation of the same images not defined.</td>
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Fracture pathology in the equine distal limb is the flexed dorsopalmar (forelimb) or plantarodorsal (hindlimb) projection. On this projection, focal radiolucency in the parasagittal groove, whether well or poorly defined, with or without increased radio-opacity in the surrounding bone, should be considered representative of fracture pathology unless evidence from other diagnostic imaging modalities demonstrates otherwise.

Computed tomography (CT) excels at identification of structural changes, resulting in greater sensitivity than radiography for detection of small fissures. However, additional research is needed to determine specific criteria for the interpretation of the significance of small lesions in the parasagittal groove with respect to imminent risk of serious injury. There are good indications that fissure lesion size and proximal sesamoid bone volumetric measurements have the potential to be useful criteria for prediction of condylar and proximal sesamoid bone fractures respectively. Results of an ex-vivo study indicated that horses with parasagittal cracks exceeding 30 mm² may be at higher risk of complete condylar fracture. The increased micromotion across the cracks of this size during high-speed exercise is thought to predispose to propagation. Equally a study using quantitative, high-resolution micro-CT, showed that a model combining bone volume fraction and width of proximal sesamoid bones had high accuracy for differentiating fracture from control horses. Although the micro-CT imaging resolutions used are not currently achievable in the clinical setting, should this change with technological advancement, CT may have an important place in quantitative risk analysis in the future.

Magnetic resonance imaging (MRI) has the ability to detect alterations in the fluid content of bones, which allows assessment of acute active changes. Indeed standing, low-field MRI has been shown to be capable of detecting bone abnormalities not readily identifiable on radiography and has been successfully used for injury mitigation in racehorse practice for some time. However, when used for evaluation of cartilage and subchondral bone lesions there is a relatively high likelihood of false-positive results. Thus MRI has a low-positive predictive value and reduced accuracy compared to CT arthrography for detection of subchondral bone lesions. MRI gives the opportunity to identify both structural and functional bone abnormalities with a single imaging technique. A study using high-field MRI established the proof of concept that greater subchondral bone depth in the parasagittal groove was associated with increased likelihood of stress fracture. Whether, with technological advances, this can be translated into a practical reality within a serial testing strategy and in the standing horse remains to be seen.

Positron emission tomography (PET)’s functional aspect shows great promise for identification of early fatigue injury and discrimination between acute, active and chronic, inactive lesions. Although relying on similar principles to bone scintigraphy, its greater spatial resolution and high lesion to background ratio leads to higher interobserver agreement and the ability to quantify changes. Early results suggest PET is extremely sensitive for detection of subchondral bone changes in both the palmar condyles and proximal sesamoid bones and an exploratory study showed PET could detect proximal sesamoid bone lesions not identified on CT or MRI. However, as with MRI and CT, there is an urgent need to determine the relevance of imaging abnormalities detected in the identification and prediction of individuals at increased risk of serious fetlock injury.

### 4 | LESSONS TO BE LEARNT FROM HUMAN SPORTS MEDICINE

A presentation on the programmes carried out on elite human athletes from Dr Rod Jaques, Director of Medical Services at the English Institute of Sport (EIS), put into sharp focus both the progress equine racecourse veterinary safety assessments have made but also the direction future efforts must take. In elite sports overseen by the EIS there is a pre-determined pathway from diagnosis of any medical condition to management of the condition identified and return of the athlete to competition. The entire pathway is implemented by
independent bodies to ensure protocols are followed and athletes fully informed of the consequences of abnormal findings prior to participation. However, whilst in some sports athletes may be given the opportunity to decline entry into the pathway, in many professional sports participation is mandatory and once entered into, the entire assessment, management and governance pathway must be completed.

Whilst veterinary assessment and regulatory pathways are in place in many racing jurisdictions globally, transparency about the process and standardisation across countries is lacking, which limits effectiveness. For optimal assessment and accurate identification of horses which are and are not fit to run there is a need for participation and respect amongst all stakeholders, underpinned by effective education and communication between parties so that trust is built. The primary care vet should be encouraged to share pertinent veterinary history where deemed necessary and within the limits of client confidentiality. This maximises information available to racecourse veterinary assessment teams and assists them in making decisions in the interests of equine welfare. Equally, owners, trainers and other stakeholders must understand their obligation to comply with the risk assessment process if they wish to enter a horse in a race. They must also respect the decisions made by regulatory vets and appreciate that these decisions are formulated based on the information and findings available at a specific point in time. Confidence in the pre-race risk assessment process will increase with greater transparency, improved communication and evidence-based decision making.

5 | ACTIONABLE ITEMS

It is clear that further research is needed to enhance knowledge in areas that will advance catastrophic fracture prevention through identification of horses with high immediate risk. The meeting identified several key areas where action could be taken:

- In light of the identification of the importance of appropriate and timely radiography for the detection of prodromal pathology, distribution of a Best Practice Guide on Fetlock Radiography to educate and enhance skills amongst primary care vets. Equine Associations internationally have been approached and asked to distribute a field guide available via the British Equine Veterinary Association.
- Collaboration with existing providers to produce educational material aimed at horsemen; to increase awareness of how serious fatigue injury develops progressively. Identification of early signs will provide the opportunity for prevention of further progression through appropriate modification of athletic activity.
- In light of the current lag between technological advancements in diagnostic imaging and knowledge of the significance of lesions identified, there is a need for creation of an international, anonymised data repository as a research tool. Archiving of standardised information on horse signalment, exercise and racing history, clinical and imaging data as well as genetic data would increase understanding of imaging findings and contribute to an overall improvement in the general health of the Thoroughbred population. It would substantially enable work on radiomics and machine learning analysis of diagnostic imaging of the fetlock, as well as epidemiology for risk profiling.

6 | FUTURE DIRECTIONS

Although huge advances have been made in recent years, many of which were highlighted in this meeting, there are still many critical gaps in the knowledge. Addressing these gaps will substantially improve risk prediction for fetlock injury in the individual horse and by proxy reduce overall racehorse attrition within the Thoroughbred industry. As well as the need to better understand imaging findings as discussed above, further work is needed to:

- Define the relationships between exercise/rest history and bone remodelling and fatigue injury.
- Identify how best to train horses to achieve race fitness whilst also optimising creation of a robust skeleton to ensure longevity.
- Identify whether genetic markers could be used in combination with environmental covariates to improve prediction of serious fetlock injury.
- Identify how rapidly fatigue injury may progress to fracture and whether there is any potential for healing and repair overtime.
- Develop a better understanding of what type of bone injuries would benefit from early surgical or medical intervention and what type of treatment may be appropriate.

Historically many of these research goals have been hampered by the difficulty in identifying an appropriate control group in study populations and the fact that data focuses on racecourse injuries rather than also including training injuries to complete the picture. We propose that to close these knowledge gaps longitudinal studies of complete populations, over significant time periods are required. An adaptive clinical trial design would allow iterative changes in study protocol to be made in light of interim findings; thus minimising ongoing horse losses through continued fatalities and attrition. Finally, what is clear is that imaging in particular, is a fast moving field and periodic revision of recommendations will be required in the future.

DATA ACCESSIBILITY STATEMENT
Data available upon reasonable request.

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AUTHOR CONTRIBUTIONS
All authors gave their final approval of the manuscript.

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OWNER INFORMED CONSENT
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SUPPORTING INFORMATION
Additional supporting information may be found online in the Supporting Information section.

APPENDIX 1.

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