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Comparison of radiography and CT for the evaluation of third carpal bone slab fractures in Thoroughbred racehorses

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Abstract

Slab fractures of the third carpal bone (C3) are a common cause of lameness in Thoroughbred racehorses. Information on fracture morphology is commonly obtained from radiographs or CT. This retrospective, methods comparison aimed to explore the agreement between radiography and CT for imaging C3 slab fractures and discuss the contribution of the latter to clinical case management. Thoroughbred racehorses with a slab or incomplete slab fracture of C3 identified on radiographs that subsequently underwent CT examination were included. Fracture characteristics (location, plane, classification, displacement, comminution) and fracture length as a percentage of the proximodistal length of the bone, termed the proximodistal fracture percentage (PFP) were recorded independently from both modalities and then compared. Across all fractures (n = 82) radiographs and CT showed slight agreement on the presence of comminution (Cohen's Kappa (κ) 0.108, *P* 0.031) and moderate agreement on fracture displacement (K 0.683, $P < 0.001$). Computed tomography identified comminution in 49 (59.8%) and displacement in nine (11.0%) fractures that were not detected by radiographs. Half of the fractures were only seen on flexed dorsoproximal–dorsodistal oblique (DPr-DDiO) radiographs and therefore were of unknown length without additional CT imaging. Incomplete fractures that could be measured on radiographs (n = 12) had a median (IQR) PFP of 40% (30%–52%) on radiographs and 53% (38%–59%) on CT, a statistically significant difference ($P = 0.026$). Radiography and CT showed the poorest agreement when determining the presence of comminution. Additionally, radiography often underestimated the incidence of displacement, and fracture length, and resulted in more fractures being classified as incomplete when compared to CT.

KEYWORDS
carpus, CT, equine, radiographs

Abbreviations: C3, third carpal bone; CR, computed radiography.; DPr-DDiO, dorsoproximal-dorsodistal oblique; DPrL-DDiMO, dorsoproximolateral-dorsodistomedial oblique; F_κ, Fleiss Kappa; IQR, interquartile range; κ, Cohen's Kappa; PFP, proximodistal fracture percentage.

1 | INTRODUCTION

Fractures of the third carpal bone are a common cause of lameness in Thoroughbred racehorses.[1–7] These generally are classified as slab fractures that extend from proximal to distal articular surfaces, incomplete (slab) fractures that involve only one subchondral bone plate, extending a variable distance into the cuboidal spongiosa or chip fractures that involve one subchondral bone plate and exit in the same joint or via a non-articular surface of the bone.[1,8] Clinical case series have reported approximately 50% of these fractures to be slab and incomplete fractures.[2,3,5,6] Arthroscopically guided lag screw fixation is the current treatment of choice, but conservative management in the case of incomplete fractures and arthroscopic fragment removal of small slab and chip fractures can also be considered.[1,8–12] Three recent publications have reported a fair to good prognosis for return to athletic function following internal fixation. In a study that included horses with complete and incomplete parasagittal slab fractures, 67% returned to racing.[13] A second study in which all horses had complete dorsal slab fractures, 42% returned to racing and the presence of displacement reduced the likelihood of racing again.[14] In a third study that included all fracture configurations, 63.1% returned to racing, with fewer horses with complete, displaced, and comminuted fractures racing again.[12]

Accurate information on fracture configuration and morphology is critical when selecting treatment, optimizing a surgical procedure and advising on prognosis. Preoperative information regarding fracture morphology has historically been obtained from radiographs, but more recently CT has become available.[7] Standing MRI has been used to assess carpal fractures and may be indicated in the absence of definitive radiographic findings or to assess involvement of soft tissues.[7,15,16] However, patient comfort level and resultant motion artefact, may in some cases preclude acquisition of diagnostic images.[7] Arthroscopy permits evaluation of fracture components visible from the middle carpal joint and has been shown to be more sensitive for detecting proximal comminution of third carpal bone slab fractures than radiography.[12] Computed tomography has been found to provide superior information than radiography for fractures of the metacarpo/metatarsophalangeal joints[17] and tarsus.[18] In humans, CT has been shown to diagnose radiographically occult carpal fractures and assist with surgical planning.[19] There is currently no published data comparing radiographic and CT evaluation of equine carpal fractures.

This study aimed to explore the agreement between radiography and CT for imaging third carpal bone slab fractures and to discuss the potential contribution of the latter to clinical case management. The working hypotheses were that radiographs and CT would (1) frequently disagree on the classification of incomplete and complete fractures, (2) that CT would more frequently depict the proximodistal length of incomplete fractures, and (3) that CT would identify comminution and displacement more frequently.

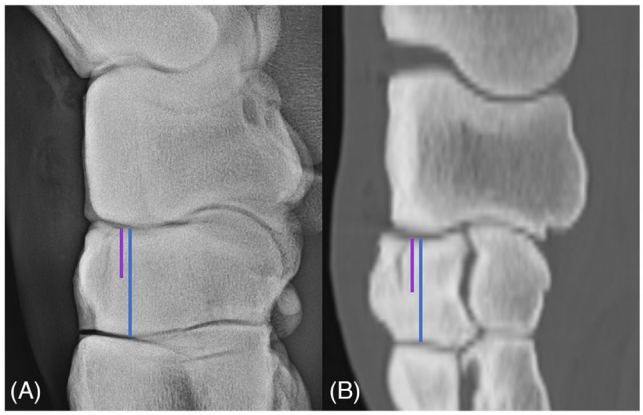

FIGURE 1 Lateromedial radiograph (A) and multiplanar reconstructed computed tomographic image (B) of an incomplete fracture of the third carpal bone. Lines are present to illustrate the measurements used to calculate the proximodistal fracture percentage (PFP). Fracture length is measured from the proximal articular margin to the most distal identifiable extent of the fracture (purple line). The proximodistal depth of the bone is the distance between its proximal and distal articular margins at the same point, on the same image (blue line). PFP = purple length/blue length × 100. (Radiographs: CR, 68 kVp and 10 mAs, 1 m film to focal-spot distance. CT: Axial acquisition, 120 kV and 300 mAs, 512 × 512 matrix, 1.25 mm slice thickness, WW: 2800, WL: 800, bone kernel reconstruction). [Color figure can be viewed at wileyonlinelibrary.com]

2 | MATERIALS AND METHODS

2.1 | Selection and description of subjects

In this retrospective methods comparison study, hospital records for all horses undergoing CT of the carpus at Newmarket Equine Hospital from November 2014 to June 2021 were reviewed. Thoroughbred racehorses that had a slab or incomplete slab fracture of the third carpal bone previously identified on radiographs were selected for inclusion. Horses that had chip fractures or other abnormalities on radiographic examination were excluded. Ethical approval was not required according to the policy of the Clinical Research Ethical Review Board at The Royal Veterinary College and the hospital director at Newmarket Equine Hospital approved the use of the images for the study.

2.2 | Data recording and analysis

All included carpi were evaluated using a standardized protocol of six radiographic projections (dorsopalmar, lateromedial, dorsolateral-palmaromedial oblique, dorsomedial-palmarolateral oblique, flexed lateromedial, and flexed dorsoproximal-dorsodistal oblique [DPr-DDiO] positioned to evaluate the distal row of carpal bones). In many cases, slight variations of each projection were also obtained to better evaluate fracture configurations and characteristics. This included the use of a flexed dorsoproximolateral–dorsodistomedial oblique

TABLE 1 Radiographic and computed tomographic fracture characteristics of 82 fractures of the third carpal bone that radiographically appeared as slab or incomplete slab fractures.

Characteristic	Radiographs	Computed tomography
Location		
Radial facet	72 (87.8%)	68 (82.9%)
Intermediate facet	3 (3.6%)	2 (2.4%)
Both facets	7 (8.5%)	12 (14.6%)
Plane		
Dorsal	50 (60.9%)	49 (59.7%)
Sagittal	31 (37.8%)	31 (37.8%)
Complex	1 (1.2%)	2 (2.4%)
Classification		
Incomplete slab	53 (64.6%)	40 (48.7%)
Complete slab	29 (35.3%)	37 (45.1%)
Chip	0 (0.0%)	5 (6.0%)
Displaced	21 (25.6%)	28 (34.1%)
Comminuted	11 (13.4%)	60 (73.1%)

(DPrL-DDiMO) projection for parasagittal fractures that were not readily visualized on other projections.[20] Radiographs were obtained using a ceiling mounted high voltage X-ray generator (Shimadzu UD150B-40, Tokyo, Japan) and a computed radiography (CR) system (Fujifilm, FCR IR-CL, Tokyo, Japan) at 68 kVp and 10 mAs. Computed tomography images were acquired under general anesthesia immediately prior to surgery using an 8-slice portable CT scanner with a 250 mm field of view (Neurologica CereTom®, Danvers, Massachusetts, USA). Axial scans were acquired from distal radius to proximal metacarpus at 120 kV and 300mAs, with a 512 × 512 matrix, 1.25 mm slice thickness, in a bone window (WW:2800, WL: 800) with a bone kernel reconstruction. All CT acquisitions were performed within 24 h of the respective radiographic examination. Images were stored on the hospital picture archiving and communications system and viewed using the same data retrieval system (Horos v3.3.5).

All images were reviewed independently by all the authors which included an equine radiology resident (R.F.D.), an European College of Veterinary Diagnostic and Imaging-certified radiologist with 25 years' experience (G.J.M.) and an European College of Veterinary Surgery-certified equine surgeon with over 40 years' experience (I.M.W.). Fracture characteristics were recorded using the same protocol, first from the radiographs and subsequently, from the CT images (with multiplanar reconstruction performed as needed). The authors were blinded to the radiographic findings for the CT interpretation. The images were viewed chronologically with a period of 2 weeks left between the data recording for each modality. Fracture information recorded included location (radial facet, intermediate facet, or both facets), plane (dorsal, parasagittal, or complex), classification (slab, incomplete slab, chip), displacement (yes, no), and presence of comminution (yes, no). Fractures were defined as slabs if the fracture extended from the proximal to distal articular surfaces of the bone, as incomplete slabs if they involved only one subchondral compacta and extended a variable distance into the cuboidal spongiosa and as chip fractures if they involved only one articular surface (subchondral compacta) and exited the bone in the middle carpal joint or via a non-articular surface. Fractures were described as dorsal plane if they were aligned approximately parallel to the dorsal surface of the bone and as parasagittal plane if they were oriented perpendicular to this. A fracture was classified as complex if it had dorsal and parasagittal components. Fractures were described as displaced if they were complete, with a visible fracture gap and there was a change in the anatomical axis of one fragment with respect to another.[21] Fractures were described as comminuted if the bone was divided into three or more discrete fragments.[22] Interobserver agreement for these categorical variables was calculated. When there was disagreement, the images were re-evaluated as a group and a consensus reached, resulting in a single final data set that was used for comparison between imaging modalities.

For incomplete fractures proximodistal extent was also assessed by measuring from the proximal articular margin to the most distal identifiable fracture line with a digital caliper (Figure 1). To account for radiographic magnification, this was expressed as a percentage of the full proximodistal depth of the bone measured at the same point, on the same image. This was performed by all authors together and was termed the proximodistal fracture percentage (PFP).

2.3 | Statistics

Descriptive statistics were performed with fracture characteristics of both modalities presented as counts and percentages. For the categorical variables interobserver agreement was evaluated using Fleiss Kappa. For variables in which there was strong agreement between imaging modalities (e.g., location and plane), individual cases with disagreement were reported. For all other variables cross-tabulation and a Cohen's Kappa test for agreement between modalities was performed with statistical significance set at $P < 0.05$. For the classification variable with three outcomes (slab, incomplete slab, chip), a Cohen's Kappa was performed to test for agreement on the presence or absence of each outcome.

For the assessment of proximodistal fracture percentage (PFP), cases were put into two groups based on the radiographic findings. Group 1 consisted of fractures that were only identified on DPr-DDiO projections and therefore the PFP could only be determined from CT images. For group 1 fractures, the median and interquartile range of the CT PFPs were reported as the data were not normally distributed on assessment of a histogram and Shapiro–Wilk testing. Group two consisted of radiographically incomplete fractures in which the PFP could be calculated and for these cases a Wilcoxon signed-rank test was used to compare the radiographic and CT PFPs as the data based

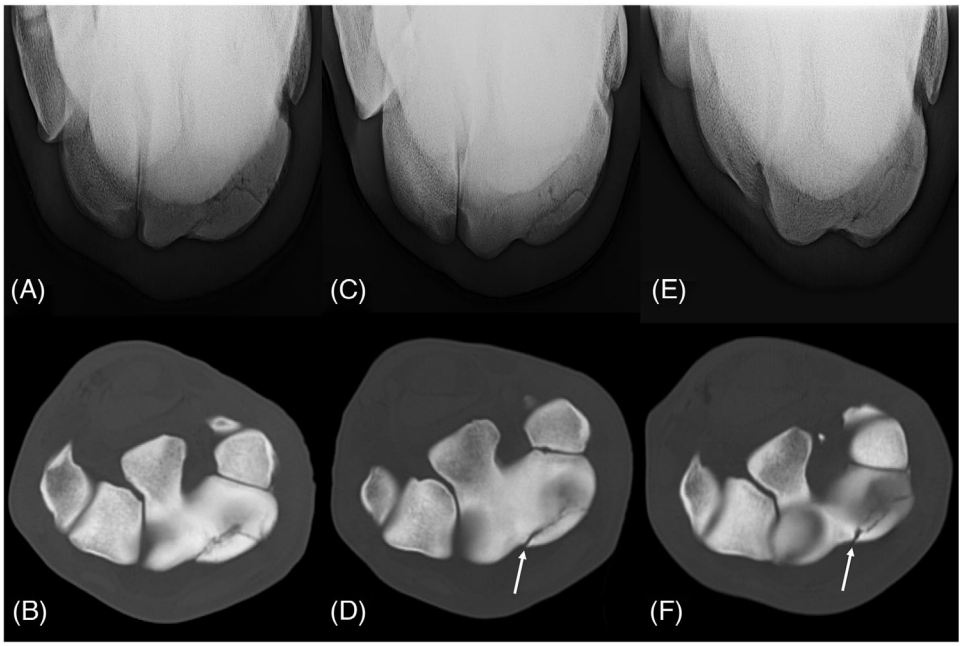

FIGURE 2 Flexed DPr-DDiO radiographs (A,C,E) and transverse CT images at the level of the proximal subchondral bone plate of the third carpal bone (B,D,F) of three horses. A,B, The radiograph demonstrates a dorsal plane fracture of the third carpal bone while the CT image shows there is an additional dorsal plane fracture in the medial aspect of the radial facet, therefore it was classified as complex. C–F, The radiographs identify non-displaced dorsal plane fractures of the third carpal bones while the CT images demonstrated a broad fracture gap with misaligned dorsal margins, these were therefore classified as displaced (white arrows). These cases (C,E) also showed no evidence of displacement on any other radiographic projection. (Radiographs: CR, 68 kVp and 10 mAs, 1 m film to focal-spot distance. CT: Axial acquisition, 120 kV and 300mAs, 512 × 512 matrix, 1.25 mm slice thickness, WW: 2800, WL: 800, bone kernel reconstruction).

on the same assessment was again not normally distributed. SPSS Statistics 28.0.0.0 (IBM software) was used for statistical analyses, and this was performed by a resident with postgraduate training in statistics (R.F.D.) under the guidance of a professor and lecturer in statistics.

3 | RESULTS

Eighty-two horses with 82 fractures met the inclusion criteria. These included 46 left and 36 right carpi. All horses were Thoroughbreds racehorses in training and were aged 2–8 (median 3, IQR 2) years. There were 34 fillies, 35 geldings, and 13 colts. Fracture characteristics are documented in Table 1.

3.1 | Interobserver agreement

The interobserver agreement for both modalities was excellent for location (Fleiss Kappa score (F_κ): radiographs 0.922, CT 0.911), plane (F_κ: radiographs 1.0, CT 1.0) and classification (F_κ: radiographs 0.947, CT 0.899). The interobserver agreement for both modalities was good for comminution (F_κ: radiographs 0.707, CT 0.794). The interobserver agreement for displacement was good for radiographs (F_κ: 0.760) and excellent for CT (F_κ: 0.907).

3.2 | Agreement between radiographs and CT

Radiographs and CT resulted in the same fracture characteristics for all variables in 23/82 fractures (28.0%). The same fracture plane was identified on both radiographs and CT in 81 of 82 fractures (98.7%). The exception was a fracture that appeared to be dorsal on radiographs but following identification an additional dorsal plane fracture within the same facet, it was classified as complex on CT (Figure 2A,B).

Location was consistent between modalities in 73 of 82 cases (89.0%). Of the five cases where there was disagreement on facet involvement, CT classified the fractures as involving both facets but radiographs deemed four to involve only the radial facet and one only the intermediate facet.

Cross tabulation of the outcomes of radiographs and CT for classification, displacement, and comminution are presented in Table 2. Radiographs and CT resulted in the same outcome with respect to the classification of the fracture in 65 of 82 cases (79.2%). The greatest agreement occurred in determining presence of a slab fracture, however, this was still only moderate (κ 0.699, $P < 0.001$). The poorest agreement occurred when determining if a slab fracture was incomplete (κ 0.588, $P < 0.001$). A κ-value could not be calculated for agreement on the presence of chip fractures as those identified radiographically were excluded from the study. In 15 cases, slab fractures were classified as incomplete from radiographs but CT demonstrated 10 to be complete slab fractures and five to be chip fractures.

TABLE 2 Cross-tabulation of radiographs and CT for the presence "yes" or absence "no" of, an incomplete slab fracture, a complete slab fracture, a chip fracture, displacement and comminution, for 82 third carpal bone fractures.

		CT		
Fracture description	**Radiographs**	**Yes**	**No**	**Total**
Incomplete slab fracture	Yes	38	15	53
		46.3%	18.3%	64.6%
	No	2	27	29
		2.4%	32.9%	35.4%
	Total	40	42	82
		48.8%	51.2%	100.0%
Complete slab fracture	Yes	27	2	29
		32.9%	2.4%	35.4%
	No	10	43	53
		12.2%	52.4%	64.6%
	Total	37	45	82
		45.1%	54.9%	100.0%
Chip fracture	Yes	0	0	0
		0.0%	0.0%	0.0%
	No	5	77	82
		6.1%	93.9%	100.0%
	Total	5	77	82
		6.1%	93.9%	100.0%
Displacement	Yes	19	2	19
		23.2%	2.4%	23.2%
	No	9	52	61
		11.0%	63.4%	74.4%
	Total	28	54	82
		34.1%	65.9%	100.0%
Comminution	Yes	11	0	11
		13.4%	0.0%	13.4%
	No	49	22	71
		59.8%	26.8%	86.6%
	Total	60	22	82
		73.2%	26.8%	100.0%

Radiographs and CT showed moderate agreement on the presence of displacement (κ 0.683, $P < 0.001$) having the same outcome in 71/82 cases (86.5%). CT predicted a higher prevalence of displacement with 9 (11.0%) fractures identified as displaced on CT that were classified as non-displaced on radiographs (Figure 2C–F). Radiographs predicted 2 (2.4%) fractures to be displaced that were non-displaced on CT.

Radiographs and CT showed slight agreement on the presence of comminution (κ 0.108, $P = 0.031$) resulting in the same outcome in 33 of 82 cases (40.2%). When disagreement occurred, CT predicted a higher prevalence, detecting comminution in 49 (59.8%) fractures that radiographs determined to be simple (Figure 3).

3.3 | Proximodistal fracture percentage

Fractures were only visible on DPr-DDiO radiographs in 41 of 82 (50%) cases and were categorized as group 1. On CT images 10 of these were classified as complete slab fractures (PFP = 100%) and the remaining had a median (IQR) proximodistal fracture percentage (PFP) of 57% (40%–87%).

There were 12 (15%) fractures in group two. These had a median (IQR) PFP of 40% (30%–52%) on radiographs and 53% (38%–59%) on CT that was a statistically significant difference ($P = 0.026$). Thirty cases were classified as complete slab fractures on both modalities and were not included in this part of the analysis.

4 | DISCUSSION

The findings of this study suggest that there can be substantial disagreement between radiographs and CT on the morphology of third carpal bone slab fractures. The modalities showed moderate agreement on fracture classification and displacement, slight agreement on the presence of comminution and there were few cases where there was disagreement on location and plane. Computed tomography predicted a higher frequency of complete, displaced, and comminuted fractures than two-dimensional radiographs. Computed tomography always provided evaluation of the proximodistal fracture length, but in 50% of cases radiographs could not. Where comparison was possible, CT yielded greater median PFP than radiographs that was statistically significant. The interobserver agreement was similar for both modalities, but for displacement it did improve from good with radiographs to excellent with CT. For classification, the interobserver agreement was excellent for both modalities, but did decrease from 0.947 with radiographs to 0.899 with CT. This may be because 50% of the fractures where only visible on a DPr-DDiO radiograph, resulting in likely classification as incomplete. These findings support the three hypotheses and suggest that radiography may underestimate the degree of comminution, displacement, and the fracture length of third carpal bone slab fractures.

A radiographic study of 371 third carpal bone fractures found that 34% were displaced and 13.8% were comminuted.[5] Slab fractures in isolation have been reported to have a higher rate of comminution (39.5%–63.4%).[12,14] These figures are comparable to the radiographic findings in this study. However, CT findings in the current study suggest that the rate of comminution in this population of Thoroughbred racehorses may be greater. Arthroscopy has been shown to be more sensitive for detecting comminution of third carpal bone slab fractures than radiography,[12] with radiographs detecting comminution in 39.5% and arthroscopy in 59.2% of cases. In the present study, comminution was identified in 60 (73.2%) fractures that suggests either that some fragments may not be seen at arthroscopy or that this group of horses had a higher prevalence of comminution.

Both radiography and CT provide high-resolution detailed images but a CT is a cross-sectional technique that may be more sensitive for the detection of comminution and displacement. Radiography is a powerful diagnostic tool that is portable, accessible, and cost effective.[7] Its limitations in this location may be due to some unavoidable features of carpal radiographs. Fractures of the third carpal bone are frequently only observed on the flexed DPr-DDiO projection.[5,20] A well-positioned flexed DPr-DDiO radiograph is invariably slightly distorted as a result of the technique. This occurs as the detector and X-ray beam are not perpendicular, producing an image that is not a true anatomical representation of the third carpal bone. In the absence of fragment distraction fracture identification requires approximate alignment of the X-ray beam and the osseous discontinuity[7] that is not achieved in this instance. In the authors' experience this can result in fracture lines appearing broad and irregular. Chronicity can also result in this appearance, due to osteolysis and widening of the fracture gap.[23] Therefore, in this study, a broad irregular fracture line without separate discrete fragments was not deemed evidence of

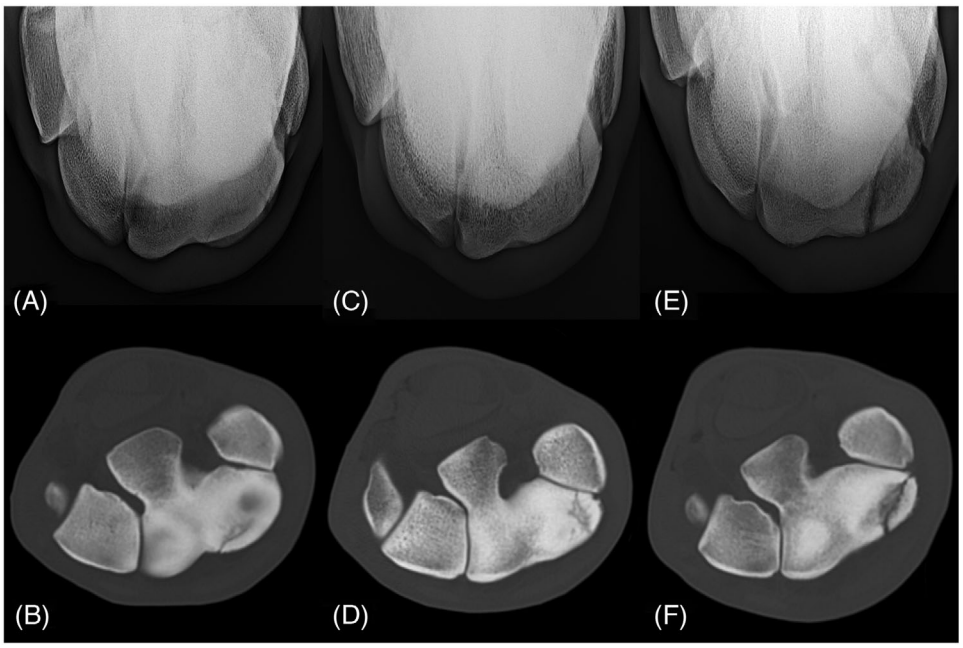

FIGURE 3 Flexed DPr-DDiO radiographs (A,C,E) and transverse CT images at the level of the proximal subchondral bone plate of the third carpal bone (B,D,F) of three horses. A–F, The radiograph in each case demonstrates a fracture of the third carpal bone with no definitive evidence of comminution while the CT image identifies discrete fragments within the fracture gap, these were therefore classified as comminuted. These fractures showed no evidence of comminution on any other radiographic projection. (Radiographs: CR, 68 kVp and 10 mAs, 1 m film to focal-spot distance. CT: Axial acquisition, 120 kV and 300 mAs, 512 × 512 matrix, 1.25 mm slice thickness, WW: 2800, WL: 800, bone kernel reconstruction).

comminution. However, this phenomenon may be disguising subtle comminution that is then detectable on CT. Flexing the carpus generally reduces displaced fractures of the third carpal bone.[1,12] As a result, unless severe, displacement may not be seen on the flexed DPr-DDiO. Lateromedial and oblique radiographic projections are often useful when assessing displacement. However due to superimposition of the carpal bones, fracture lines may be less evident. The limb is straight when the CT scan is performed, allowing a displaced fragment to be more easily detected.

In order to preserve athletic function, if it can be done accurately and safely any fracture involving an articular surface should be reconstructed.[1,10,14] Accurate preoperative information is critical and the proximodistal length of the fracture must be understood. If the slab fracture is complete, screws should be placed at the proximodistal midpoint of the bone.[1,8] Conversely with incomplete slab or chip fractures screws will need to be placed eccentrically (commonly proximally) to be safe and effective.[24] De facto this, in turn, requires accurate and confident determination of fractures' proximodistal length. In the current study, an evaluation of fracture length was only consistently possible with CT.

Comminution may not be visible arthroscopically if it is within the fracture gap or obscured by articular cartilage. If a fracture is comminuted the surgeon must decide if fragments are to be removed or retained and secured in repair. The findings of this study suggest that two-dimensional radiography and CT often yield differing information and that CT can assist in surgical planning.

Within this study population cases were commonly selected for CT evaluation because they were potential surgical candidates. As a clinical study there is no gold standard with which to compare radiography and CT such as histopathology. As a result, sensitivity and specificity measures were not produced.[25] However, testing for agreement between these modalities should highlight to clinicians the potential limitations of radiography. Arthroscopic findings were considered as an alternative to histopathology, but arthroscopy only permits the visualization of the margins of the fracture that are within the middle carpal joint. Arthroscopy may be less sensitive than CT for the detection of the classification of the fracture or comminution that is within the fracture gap and was not used as an alternative to histopathology. An axial CT acquisition technique was used in this study. This can offer superior spatial resolution to helical scanning in the *x*–*y* plane but is more susceptible to stair step artefact commonly seen in multiplanar reconstructions in the *z*-plane.[26]

In conclusion, there can be substantial disagreement between radiographs and CT when determining the morphology of third carpal bone slab fractures in Thoroughbred racehorses. The modalities showed only slight agreement on the presence of comminution and moderate agreement on the displacement and extent of the fractures. Half of the fractures were only seen on a DPr-DDiO radiograph and had an unknown proximodistal length, which is a key limitation of two-dimensional radiography as fracture length is critical to case management. The findings support the hypotheses that CT detects a higher frequency of comminution, displacement and complete fractures than radiographs.

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LIST OF AUTHOR CONTRIBUTIONS

Category 1

a. Conception and design: Minshall, Wright
b. Acquisition of data: Dash, Minshall, Wright
c. Analysis and interpretation of data: Dash, Minshall, Wright

Category 2

a. Drafting of the article: Dash, Minshall, Wright
b. Revising article for intellectual content: Dash, Minshall, Wright

Category 3

a. Final approval of the completed article: Dash, Minshall, Wright

Category 4

a. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Dash, Minshall, Wright

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

PREVIOUS PRESENTATION OR PUBLICATION DISCLOSURE

The authors declare no previous presentations or publication.

REPORTING CHECKLIST DISCLOSURE

An EQUATOR Network checklist was not used for this study.

DATA ACCESSIBILITY STATEMENT

To access data supporting the results of this paper please contact Rupert F. Dash, rdash1@rvc.ac.uk.

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