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Original Article

The use of computed tomography to assist orthopaedic surgery in 86 horses (2002–2010)

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Keywords: horse; computed tomography; assisted surgery

Summary

Imaging-assisted orthopaedic surgery is becoming part of routine orthopaedic practice in horses and several techniques have been reported. However, there are no published reports describing the use of intraoperative computed tomography (CT) for surgical guidance and immediate post operative control in the horse. This use of CT in equine orthopaedics is currently limited because of the logistic problems associated with availability of CT scans in surgical theatres as well as concerns over radiation safety. The aim of this report was retrospectively to report CT assisted orthopaedic surgical cases in our practice through identifying the types of surgery where it was used, to list the technical problems that were encountered, to describe solutions to these, and to discuss the applications of the technique. All surgical procedures were performed with the assistance of a peripheral quantitative computed tomography (pQCT) scanner. CT assisted orthopaedic surgery in 86 patients during the study period. Reasons for CT included: 1) use of CT at the beginning of the surgical procedure to document the lesion and identify surgical landmarks (n = 75); 2) pre, intra- and post operative use of CT in comminuted fractures of the middle or proximal phalanx to guide and control internal fixation (n = 7); and 3) post operative use of CT to monitor the results of the surgical procedure (n = 4). Proper planning in both the draping steps and the use of polyvinyl splints to stabilise the limb allowed for movements of the gantry around the limb. The time required to obtain one slice was not dissimilar to the time that is necessary to take and process a single digital radiograph. The radiation dose with the pQCT described here is <0.5 µSv and its acquisition time should be balanced against radiation risks of conventional CT systems.

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Introduction

Imaging-assisted orthopaedic surgery is becoming part of routine orthopaedic practice in horses and several techniques have been reported. Conventional 2D imaging (fluoroscopy and radiography) are more commonly used to assist surgery than ultrasonography (Piccot-Crézollet and Cauvin 2005), 3D image-guided surgery (Andritzky *et al*. 2005; Gygax *et al*. 2006; Rossol *et al*. 2008) or computed tomography (CT) (Perrin *et al*. 2009). CT allows the production of cross-sectional images with spatial separation of structures that assist in identification of the number and direction of fracture lines within the bone in comminuted fractures (Rose *et al*. 1997; Martens *et al*. 1999; Waselau *et al*. 2006). The potential interest of CT to identify guidelines for internal fixation of the distal phalanx and distal sesamoid bone has also been assessed *in vitro* (Vandeweerd *et al*. 2009; Perrin *et al*. 2010). Recently, CT was shown to be a useful tool in treatment planning for disorders of the equine distal extremity (MacDonald *et al*. 2009). However, there are no published reports describing the use of intraoperative CT for surgical guidance and immediate post operative control in the horse. This use of CT in equine orthopaedics is currently limited because of the logistic problems associated with availability of CT scans in surgical theatres as well as concerns over radiation safety.

The aim of this report was retrospectively to report CT assisted orthopaedic surgical cases in our practice through identifying the types of surgery where it was used, to list the technical problems that were encountered, to describe solutions to these, and to discuss the applications of the technique. We hypothesised that CT can be used before surgery for planning, during the procedure to guide surgical steps and after to review the results of the surgery.

Materials and methods

The medical records of all horses undergoing orthopaedic surgery assisted by CT in our clinic between April 2002 and March 2010 were reviewed. Cases were selected if the CT scan was used before, during or after surgery, within one period of general anaesthesia. Cases where surgical landmarks for foot surgery were obtained on the standing horse were also included. Cases were excluded if CT failed to confirm the surgical indication or where horses were subjected to euthanasia on the table. Data collected were: indication for CT and surgery, final diagnosis, surgical procedure, technical problems associated with perioperative CT, number of slices and time to obtain these. The procedures were sorted into 3 categories: 1) preoperative use of CT to document the lesion, identify its landmarks and plan surgical portals; 2) post operative use of CT to confirm the surgical result; and 3) pre-, intra- and post operative use of CT, where more than 2 sessions of acquisition were performed during one anaesthetic period, and where CT was used to assess the lesion, guide the surgical procedure and control the results.

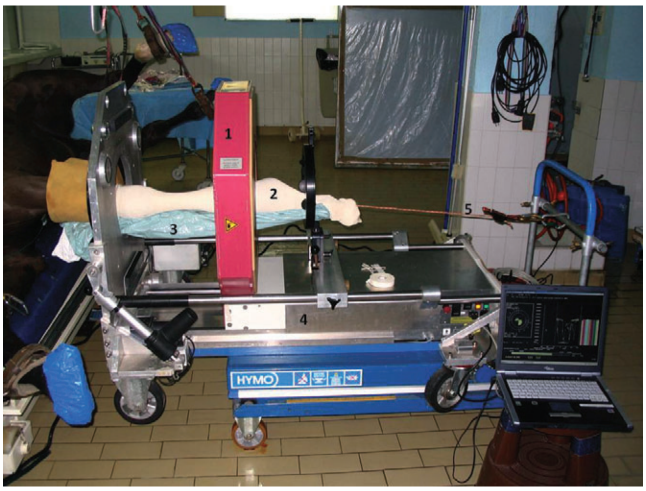

Fig 1: Forelimb positioned through the gantry (1) of the Equine XTC 3000 scanner. The limb is wrapped in stockinette (2) and laid on a splint within an arthroscopic sheath (3). Tension is applied to the distal limb via a stainless steel wire connected to the frame of the scanner (4 and 5).

All procedures were performed with the assistance of a peripheral quantitative computerised tomography (pQCT) scanner (Equine XCT 3000)[1]. pQCT is a technique used predominantly in research to assess bone mineral density. The scanner has been adapted to equine practice and to image the limbs of the horse specifically both in standing or recumbent position (Desbrosse *et al*. 2008). It weighs 200 kg and can be moved within the hospital or transported in a small car (**Figs 1** and **2**). The x-ray tube operates at a maximum 60 kV with an anode current of 0.3 mA. The mean energy is 45 keV. The exit beam is highly filtered and highly collimated so as to minimise both the patient dose and avoid handler's exposure to x-rays. The effective radiation dose is only 1.5 µSv. The gantry has an opening of 300 mm diameter. The minimal longitudinal step width for scans is 0.01 mm over a full length of 350 mm. The system uses software[1] to control the scan, display the images,

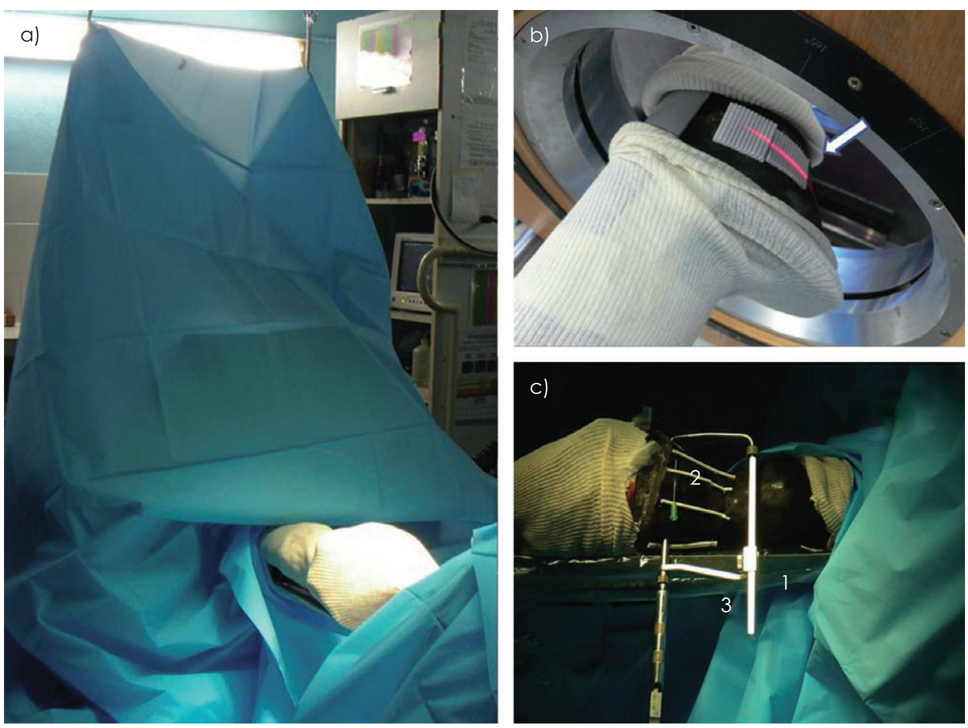

Fig 2: a) Draping of the limb and scanner. b) Foot within the gantry with radiopaque markers and laser beam. c) Splint (1), radiopaque markers (2) and C Clamp (3) used in osteosynthesis of the proximal phalanx.

measure distances and bone density. 3D images can be obtained using VolView[2] software. The CT scan is calibrated before use with a phantom provided by the manufacturer. Each slice number is associated with a position along the axis of translation of the gantry, called Z position, which is provided by the software. Once these data are known and input to the system, the CT is able to reposition itself at the exact level of the slice corresponding to that Z position. The slice corresponding to the Z position where the CT scan stops is indicated by a laser beam generated by the gantry. This feature can also be used to identify the exact position for insertion of a screw based on a previous acquisition.

Results

Patients and reasons for performing surgery

During the study period 86 horses (7 Standardbred, 60 Selle Français, 3 Thoroughbreds, one Belgian Warmblood, 5 Dutch Warmblood, 5 Hannoverian, 2 Trackener, one Arab, one Anglo-Arab, one Westphalian), aged 1 month–16 years (mean 7 years), including 30 females, 21 males, and 35 neutered males, were eligible for the study according to the inclusion criteria. Horses were used for showjumping (n = 31), dressage (n = 10), Standardbred racing (n = 7), Thoroughbred racing (n = 3), leisure (n = 30), endurance (n = 1), polo (n = 1) and breeding (n = 3). The reasons for CT scan and surgery, and types of procedure, are reported in **Table 1** and illustrated in **Figures 3–7**.

CT scan procedure

In all cases, either in standing patients or in recumbency under general anaesthesia, a preliminary scan (scout view) was made to plan the slices. Then 1–10 transverse CT slices were made, separated from 1–5 mm. Slice thickness was 1 mm. The number of slices and distance between slices varied with the anatomical region being imaged. For example, narrower slices were obtained when anatomical landmarks were identified for internal fixation of the distal sesamoid bone where very precise positioning of the implant was required to avoid penetration of the flexor or articular surface. Distance between slices was larger in fractures of the phalanges. Settings included several parameters such as voxel size (0.10–1.00 mm) and CT speed (10–50 mm/s). The time for the acquisition of one slice ranged from 60–90 s depending on the voxel size and CT speed. Commonly, voxel size was set at 0.30–0.50 mm, and CT speed at 30 mm/s. Mean time required to introduce setting parameters in the software was 2 min. Scout views were obtained more quickly with a scout view speed of 50 mm/s, CT speed of 50 mm/s and distance between slices of 5–8 mm. Mean time for a scout view was 2 min. Mean time to obtain one slice was 2 min. Less than 45 min surgical time was spent scanning in any case.

Technical issues and solutions

Surgical draping

The limb remained within the gantry during the whole procedure, which required proper draping that could accommodate the movements of the gantry for successive sessions of CT acquisition. A stainless steel wire was passed either under the branches of the shoe or through holes drilled in the hoof capsule. Traction was applied between the limb and the frame of the CT scanner in order to maintain the limb in extension. After clipping and conventional aseptic preparation of the whole distal limb, the wire was released and a long stockinette passed from the distal extremity of the wire to the proximal limb. A sterile polyvinyl chloride custom made splint was introduced in an arthroscopy camera drape and positioned through the gantry to support the limb and keep it immobile during scanning and surgery, as movement would render unreliable successive identification of landmarks based on previous CT slices (i.e. it would be useless to use the CT laser beam to identify a position at a specific site if the limb had moved in the meantime) (**Fig 1**). Fenestrated drapes were used to protect the upper and lower part of the gantry. The scanner was covered with other drapes. The upper fenestrated drape was attached loosely to the rail of a hook above the scanner so that the gantry could move back and forward without traction on the drape (**Fig 2**).

Radiopaque markers

Radiopaque markers were necessary to identify anatomical landmarks for planning of surgery, or for guiding surgical gestures during surgery. Pieces of a radiopaque tubular drain (Multitubular Drain)[3] were glued with cyanoacrylate (Colle Cyanoacrylate)[4] to the hoof or stapled to the limb (**Fig 3**). Each tubule of the multitubular drain was 2 mm in diameter. Markers were placed in sufficient number to provide enough landmarks on the limb. Single and double tubules were alternated to facilitate their identification on the CT scan. Drains were cut at various lengths depending on their use. For internal fixation of the distal phalanx or distal sesamoid bone, two 3 cm long, 2 cm wide pieces of radiopaque drain were glued on each side of the hoof, parallel to the coronary band, 1.5 cm below it at mid-distance between its dorsal and palmar aspects, over the projection area of the distal sesamoid bone or the distal phalanx.

Implants and surgical instruments

Metallic implants and stainless steel instruments may result in artefacts that distort the image (**Figs 4** and **7**). This was solved by obtaining the slices in a transverse plane slightly

TABLE 1: Indication for scanning, final diagnosis, and surgical procedure or treatment for the 86 clinical cases included in this study

Reason for CT scan	No. of cases	Final diagnosis and surgery or treatment
Preoperative planning in standing position	4 cases	
Keratoma in a forefoot	2	The direction and extent of keratoma was identified with markers in all cases. Those landmarks were used for surgery.
Sagittal fracture of P3	1	The direction and length of implant were evaluated and the landmarks identified by markers were used at surgery (internal fixation).
Chronic foot abscess	1	Significant pedal osteitis was diagnosed and followed by surgical curettage under general anaesthesia.
Preoperative planning under general anaesthesia	71 cases	
Fractures of distal bones	18	Fractures were confirmed and direction and length of implant were identified preoperatively in sagittal fracture of distal phalanx (n = 2), comminuted fracture of middle phalanx (n = 2), comminuted fractures of proximal phalanx (n = 4), simple sagittal fractures of proximal phalanx n = 8), sagittal fracture of distal sesamoid bone (n = 1), spiral fracture of MC 3 (n = 1)
Subchondral bone cysts of phalanges	1	CT was used at surgery to localise and inject a cyst in the distal phalanx
Foot penetration	1	Confirmation of DDFT lesion and penetration of navicular bursa by contrast CT, followed by 'street nail surgery'.
Wound and foreign body at the coronary band	1	CT was used at surgery to localise and assess the depth of penetration of a foreign body at the coronary band.
Keratoma in a hind foot	3	The direction and extent of keratoma was identified.
Osteochondral fragments in distal joints	6	Identification of anatomical landmarks for removal of osteochondral fragments in the distal interphalangeal joint (n = 1) and metacarpo/tarso-phalangeal joint (n = 5).
Fresh wound on dorsal aspect of the fetlock	1	CT was used to evaluate the presence and extent of foreign body in a wound.
Pastern osteoarthritis	1	Evaluation of direction and length of implants for surgical joint arthrodesis.
High suspensory desmitis	21	In 16 horses, CT was performed before osteostyxis to identify the sites where MC/MT 3 was remodelled. In 3 other cases, extensive exostosis (spurs) was diagnosed and was removed surgically. In one case, a stress fracture was visualised and enostosis was diagnosed in another; on both horses, an osteostyxis was performed.
Splint bones exostosis	9	CT was used to assess the extent of the exostosis and its potential impingement on the suspensory ligament before surgical removal.
Sequestrum of MC III	3	CT was used to assess the extent and anatomical landmarks of a sequestrum of a third metacarpal bone.
Osteochondral fragments and bone cysts in proximal joints	4	Identification of anatomical landmarks for removal of osteochondral fragments in the hock (n = 2), stifle (n = 2) and carpus (n = 1), and injection of a bone cyst in third carpal bone (n = 1).
Fractures of proximal bones	2	Fractures were confirmed and direction and length of implant were identified preoperatively in fracture of distal radius (n = 1), tibial crest (n = 1).
Post operative control	4 cases	
Splint bone exostosis	1	CT was used to assess the landmarks for split bone removal. Outcome was checked at the end of the procedure.
Spur on *sustentaculum tali*	1	CT was used to assess removal of a spur on the *sustentaculum tali*. Currently, initial surgical steps did not succeed in removing it and the second scanning indicated that further curettage was necessary.
Third carpal bone fracture	1	Proper placement of the screw in the transverse plane of the bone was assessed by CT after surgery.
Sagittal fracture of the distal phalanx	1 (GA)	CT was used to plan surgery and control proper placement of the screw.
Pre-, intra- and post operative scanning	7 cases	CT was used to place screws in comminuted fracture of middle phalanx (n = 3) and comminuted fractures of proximal phalanx (n = 4). After identification of anatomical landmarks, the first screw was placed. Then another scan was performed to assess reduction and identify the landmarks for the second screw. This was repeated until the fracture was satisfactorily fixed.

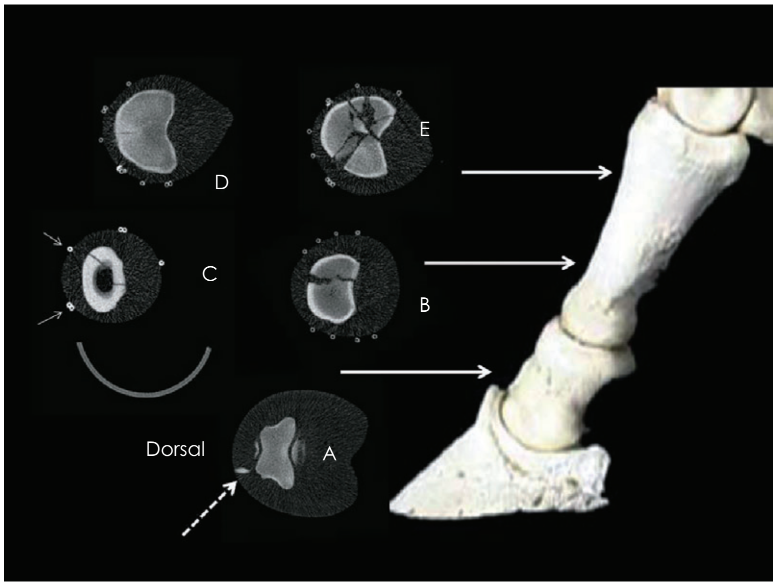

Fig 3: Cases where CT was performed for surgical planning: (A) foreign body (dotted white arrow) at the coronary band; (B, C, D, E) complete sagittal, spiral, simple incomplete, comminuted fractures of P1. Note the radiopaque markers (plain small arrows).

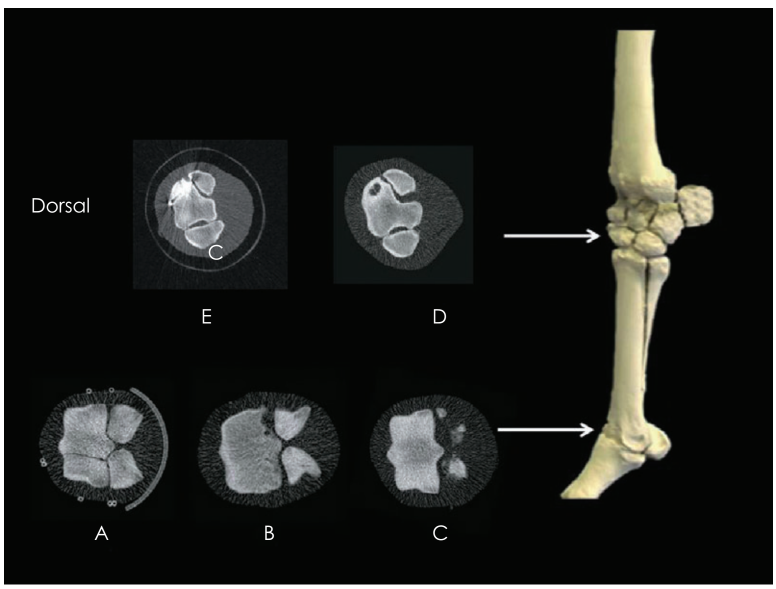

Fig 4: Cases where CT was performed to plan surgery and to confirm surgical result: (A) condylar fracture; (B) supracondylar lysis in palmar MC III; (C) fragmentation of distal aspect of proximal sesamoid bones; (D) osseous cyst-like lesion in third carpal bone; (E) sagittal fracture of third carpal bone treated by internal fixation. Note the artefact generated by the screw.

distal or proximal to the screw. Positioning of forceps was also determined by subsequent scanning and was therefore not always ideal.

Discussion

This descriptive study has shown that pQCT may be successfully used to facilitate different equine orthopaedic surgical procedures under general anaesthesia. CT scanning of the front foot in the standing horse was also used successfully to identify surgical landmarks before a procedure, thereby facilitating surgery and reducing anaesthetic time. However, in this case series, standing CT was used in only 4 cases prior to surgery. We only saw a few relevant cases for which intraoperative foot CT was indicated. Furthermore, conditions that affect hind feet, or that are associated with severe lameness, are not amenable to standing CT.

As demonstrated and illustrated in previous reports by MacDonald *et al*. (2009) and Desbrosse *et al*. (2008), the use of CT enabled imaging and documentation of lesions of the distal limb. In this case series, CT was also used for conditions of more proximal regions such as the stifle (2 cases) and the proximal tibia (one case). However, the size

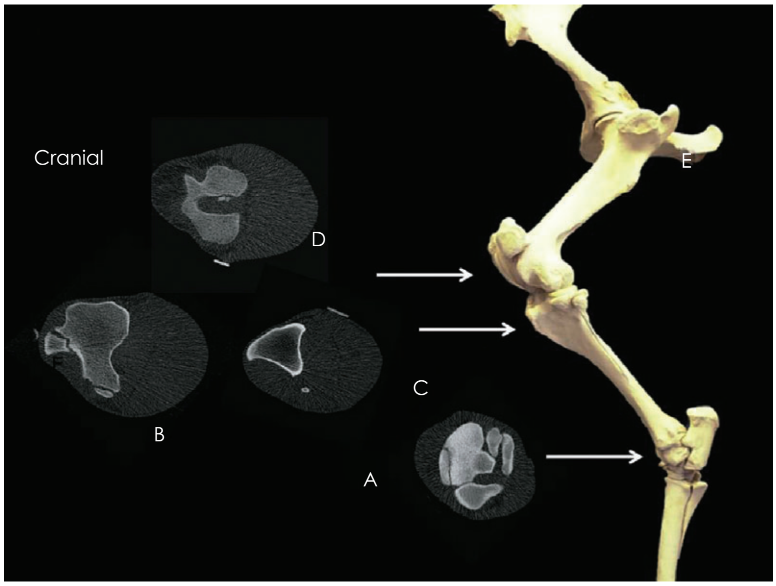

Fig 5: Cases where CT was used in proximal anatomical regions of the pelvic limb. (A) fracture of the central tarsal bone; (B) fracture of the tibial crest; (C) bone fragment near proximal tibia; (D) bone fragment in the intercondylar space of distal femur.

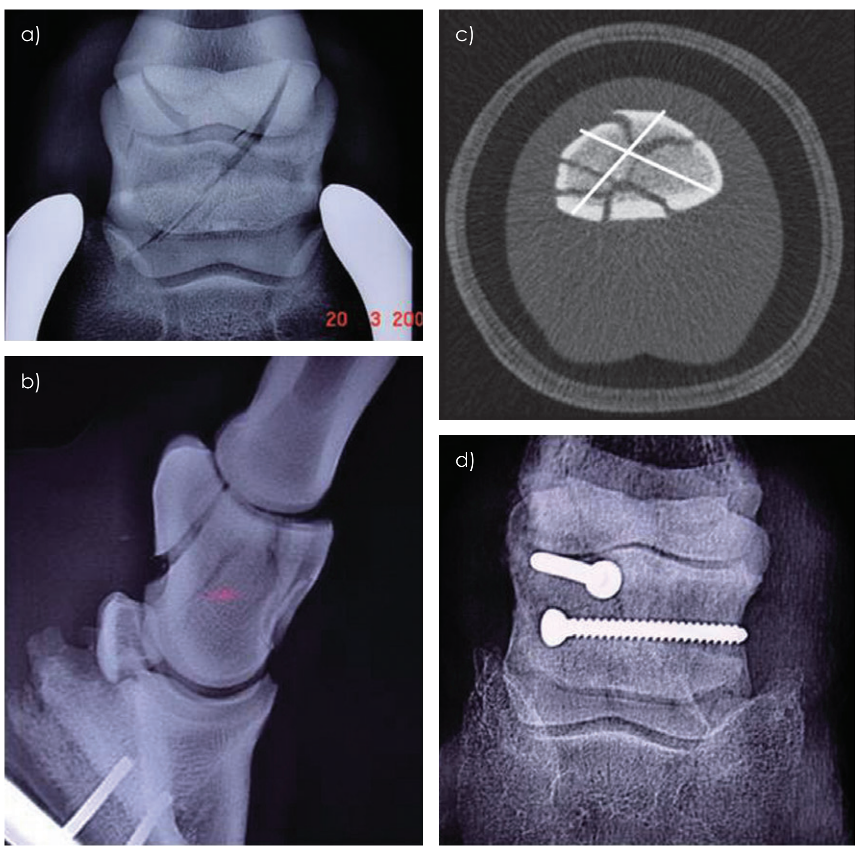

Fig 6: This figure illustrates the difficulty to assess fracture lines with conventional radiography (a and b) and the use of CT for planning the direction of surgical implants (c). Picture d) illustrates the final placement of the screws.

of the gantry limited investigation of very proximal joints to small sized horses or foals.

Other authors have reported the use of CT to identify preoperative guidelines (Rose *et al*. 1997; Martens *et al*. 1999; Waselau *et al*. 2006; MacDonald *et al*. 2009). This study also illustrated potential uses of CT before surgery to identify the localisation and extent of keratoma and distal phalanx osteitis, to localise osteochondral or bone

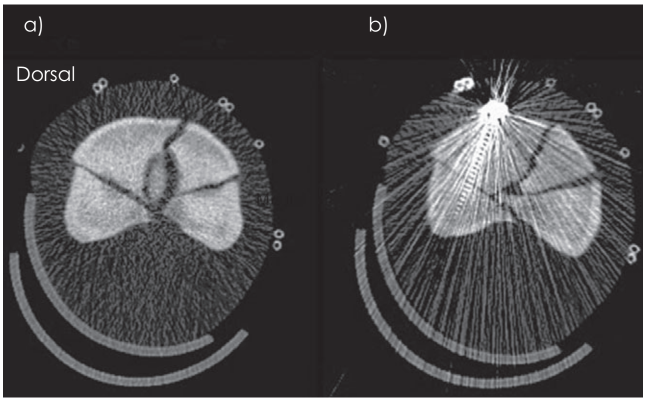

Fig 7: a) is a preoperative scan of a comminuted fracture of P1. b) is the perioperative scan after placement of the first screw. Note the artefact generated by the screw.

fragments in or near joints, to assess the position and extent of exostoses or bone remodelling, to evaluate the direction and length of implant in internal fixation, to localise subchondral bone cysts before injection with steroids, and to evaluate the localisation and extent of foreign bodies in wounds or sequestra.

In our case series, pQCT was used to assess surgical outcome at the end of the procedure in 4 cases. Adequate placement of screws, removal of splint bone exostosis and curettage of a spur on the *sustentaculum tali* were monitored post operatively. Conventional CT scans are not transportable and are rarely available in the surgical theatre. It is frequently not practical to move a horse after the procedure from the theatre for scanning, especially if the results mean that the horse may have to be returned to the theatre for further surgery. This is a reason why conventional imaging (radiography, fluoroscopy) is usually preferred for such monitoring when conventional CTs are available. It is our experience that postoperative review obtained by pQCT provides superior information to the 2D review of the type obtained by fluoroscopy or radiography. It is significant that post operative review was still useful because one case (spur on the *sustentaculum tali*) required further intervention and curettage based on scan results carried out at the end of surgery.

To our knowledge, this is also the first report of the intraoperative use of CT. Conventional CT is little used intraoperatively for logistical and safety reasons. CT is one of the largest contributors to man-made radiation doses amongst medical staff (Semelka *et al*. 2007). The principal concern regarding radiation exposure is that the subject may develop malignancies. The Food and Drug Administration (FDA) estimates that a CT examination with an effective dose of 10 mSv may be associated with an increased chance of developing fatal cancer for approximately one patient in 2000 (Semelka *et al*. 2007). For example, effective doses of 6.7–13.0 mSv were observed when coronary angiography was performed with a multi-detector row CT. The mean level of exposure to natural background radiation each year in Germany is 2.4 mSv/year and the dose delivered at conventional chest radiography is 0.2 mSv (Hunold *et al*. 2003). For comparison, the radiation dose with the pQCT described here is <0.5 μSv per slice in a human radius and <1.5 μSv for a human femur. This is an advantage when multiple slices must be obtained during a surgical procedure such as internal fixation.

Anatomical bone fracture reduction is pre-requisite for a successful outcome following internal fixation (Auer 2006). The information traditionally available to the surgeon during the reduction manoeuvre can be divided into visual and tactile information. The optimal implementation of these parameters, combined with the surgeon's individual experience, will significantly affect the results of the operation. In the case of comminuted fractures of the phalanges, despite intraoperative radiography or fluoroscopy, an open approach may be necessary to assess fracture lines and delineate the full extent of any comminution (Nixon 2006). Using computed assisted radiography (Andritzky *et al*. 2005) or CT (Perrin *et al*. 2009) may facilitate accurate reduction without the invasive visual inspection.

Intraoperative use of pQCT presents several problems and limitations. Metallic implants and instruments cause artefacts that may obscure the area of interest. For that reason, reduction forceps cannot always be placed in their optimal position. There is a requirement for technical advances, for instance in the development of nonmetallic reduction devices.

Another limitation is the time of acquisition of the pQCT in comparison to more powerful scanners. Nevertheless, the time required to obtain one slice is not dissimilar to the time necessary to take and process a single digital radiograph in our practice as, despite a powerful DR system, the plate still needs to be processed outside the theatre. Furthermore, this disadvantage should be balanced against radiation risks of conventional CT systems.

Draping was another issue as it has to allow for movements of the gantry. Proper planning in both the draping steps and the use of polyvinyl splints to stabilise the limb resolved the problem, especially as the gantry has only a small surface requiring draping.

Though we report our positive experience with the system, owing to the variety of the cases we were unable to compare CT assisted surgery to conventional techniques such as radiography and fluoroscopy. We acknowledge also that some of our examples are overstating the use of CT. Splint bone removal in conventional traumatic fractures of a lateral MT4 does not need the use of CT scan. Internal fixation of a sagittal fracture of the third carpal bone can be routinely performed with a combination of arthroscopy and radiographs. If we used CT even in simple cases, it was to improve our technique and training. The study therefore remains purely descriptive and was not intended to demonstrate the superiority of the system. However it may be a useful demonstration of what can be achieved by CT assisted surgery and a guide for practitioners who wish to develop the technique.

Manufacturers' addresses

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