Paper

Radiographic anatomy of juvenile bovine limbs

S. E. Hoey, A. H. Biedrzycki, M. J. Livesey, R. Drees

Juvenile bovine patients who present with clinical signs of lameness are commonly evaluated using radiographic techniques both within a hospital setting and in a farm environment. The radiographic development of the juvenile bovine skeleton is currently poorly documented. In this study, the limbs of four heifer calves were sequentially radiographed to assess development of the juvenile bovine appendicular skeleton in the first 12 months of life. Images were acquired at three weeks, three months, six months, nine months and one year of age. The normal radiographic anatomy of the fore limbs and hindlimbs and the changes over the first 12 months are described. The majority of physes remain open throughout this period, with the exception of the proximal physes of the proximal and middle phalanges, the proximal radial physis, and the proximal humeral physis which close radiographically between 9 months and 12 months of age, and fusion of the fourth and central tarsal bones occurs between 9 months and 12 months of age. The results of this study may aid in differentiating normal and abnormal anatomy in the juvenile bovine limb.

Introduction

Juvenile cattle presenting with lameness are commonly evaluated for traumatic, congenital or infectious disorders as an underlying aetiology. Radiography is frequently utilised as an essential first line diagnostic tool for the evaluation of pathology in foals. Bovine patients can similarly be evaluated as part of a thorough workup, although there is very little available reference data for the juvenile bovine radiographic anatomy. Currently, existing references were acquired using film radiography and are comparatively of inferior quality to images, which can be acquired using computed and digital techniques (Geissbühler and others, Pernell and others 1992, Bargai 1993, Ebeid and Steiner 1996, Pharr and Bargai 1997, Falstead 2009, Kolfer and others 2014). One online resource provides a reference for normal and abnormal radiographic anatomy of the adult and juvenile bovine patient (Bargai and others 1989). This resource is not peer reviewed, however, and there are few images of normal juvenile bovine subjects over more than one time point.

With development of the skeletal system, subtle changes occur which may be mistaken for pathology, and there is a paucity of resources available which document the normal radiographic features of the progressively maturing bovine skeleton. Similarly subtle pathological changes may be mistaken for normalcy without adequate reference available. The purpose of this study was to create a reference of the clinically normal juvenile bovine limb anatomy, from neonate to 12 months of age.

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Methods and materials

Four neonatal female Holstein-Friesian calves were randomly selected from a private dairy farm. The calves selected had no history of clinical disease, and were normal on clinical examination at all time points. Calf handling and radiography was performed according to approved Animal Care and Use Protocol Guidelines of the University of Wisconsin-Madison, Research Animal Resource Center Mild sedation with xylazine (0.1–0.2 mg/kg intravenously, Anased, Akorn Decatur, Illinois, USA) was administered if advocated to facilitate safe image acquisition. The calves were radiographed at five time points: at 3 weeks, 3 months, 6 months, 9 months and 12 months of age. Before acquisition of the

TABLE 1: List of the 23 views acquired of each side of the four subjects at the five time points (3 weeks, 3 months, 6 months, 9 months, 12 months)

Fore feet	Dorsopalmar Lateromedial
Metacarpophalangeal joints	Dorsopalmar Lateromedial
Carpus	Dorsopalmar Lateromedial Dorsolateral-palmaromedial oblique Dorsomedial-palmarolateral oblique Flexed lateromedial Dorso35°proximal-dorsodistal oblique Dorso55°proximal-dorsodistal oblique
Cubital joints	Craniocaudal Lateromedial
Shoulder	Caudolateral-craniomedial oblique Mediolateral
Hind feet	Dorsoplantar Lateromedial
Metatarsophalangeal joints	Dorsoplantar Lateromedial
Tarsus	Dorsoplantar Lateromedial Dorsolateral-plantaromedial oblique Dorsomedial-plantarolateral oblique Plantaroproximal-plantarodistal oblique

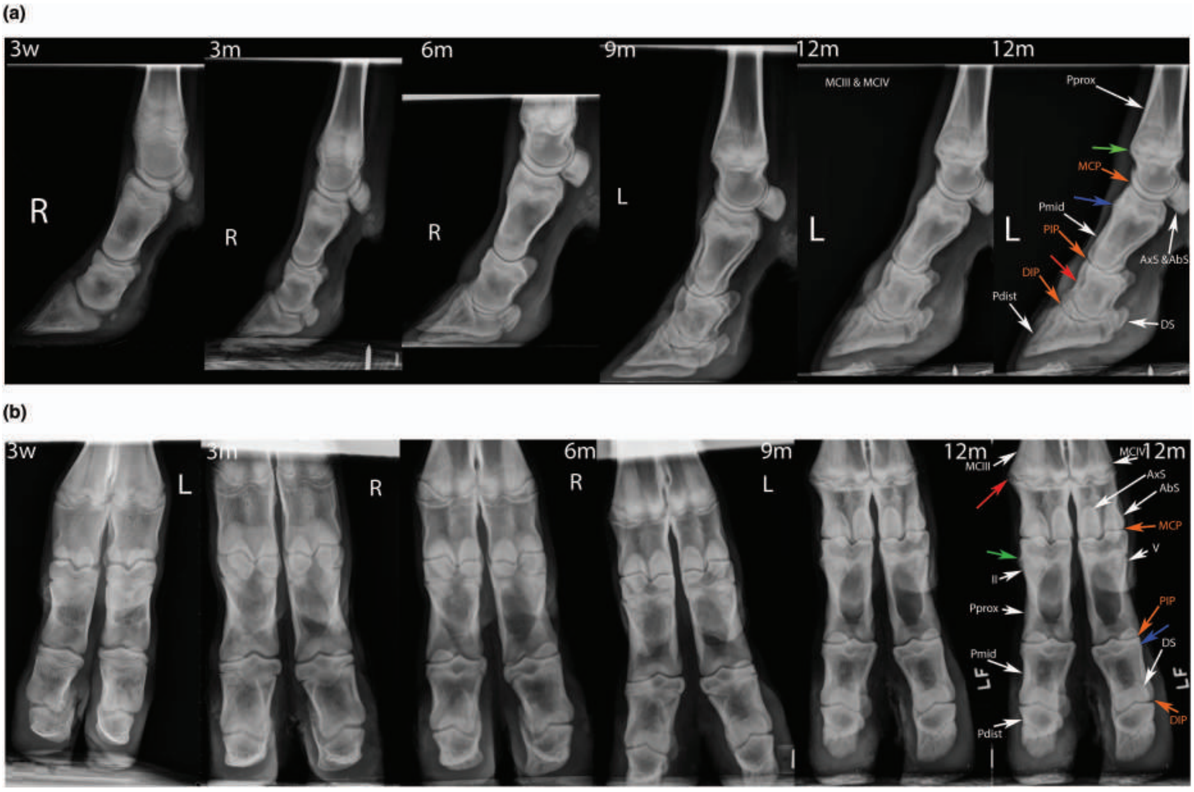

FIG 1: Forefoot: (a) lateromedial and (b) dorsopalmar views 3 weeks, 3 months, 6 months, 9 months and 12 months. Red arrow, distal metacarpal physis. Green arrow, proximal phalanx of the proximal phalanx. Blue arrow, proximal physis of the middle phalanx. MCIII third metacarpal bone; MCIV; fourth metacarpal bone; AxS, axial sesamoid bone; AbS, abaxial sesamoid bone; II, second digit; V, fifth digit; Pprox, proximal phalanx; Pmid, middle phalanx; Pdist, distal phalanx; DS, distal sesamoid; MCP, metacarpophalangeal joint; PIP, proximal interphalangeal joint; DIP, distal interphalangeal joint

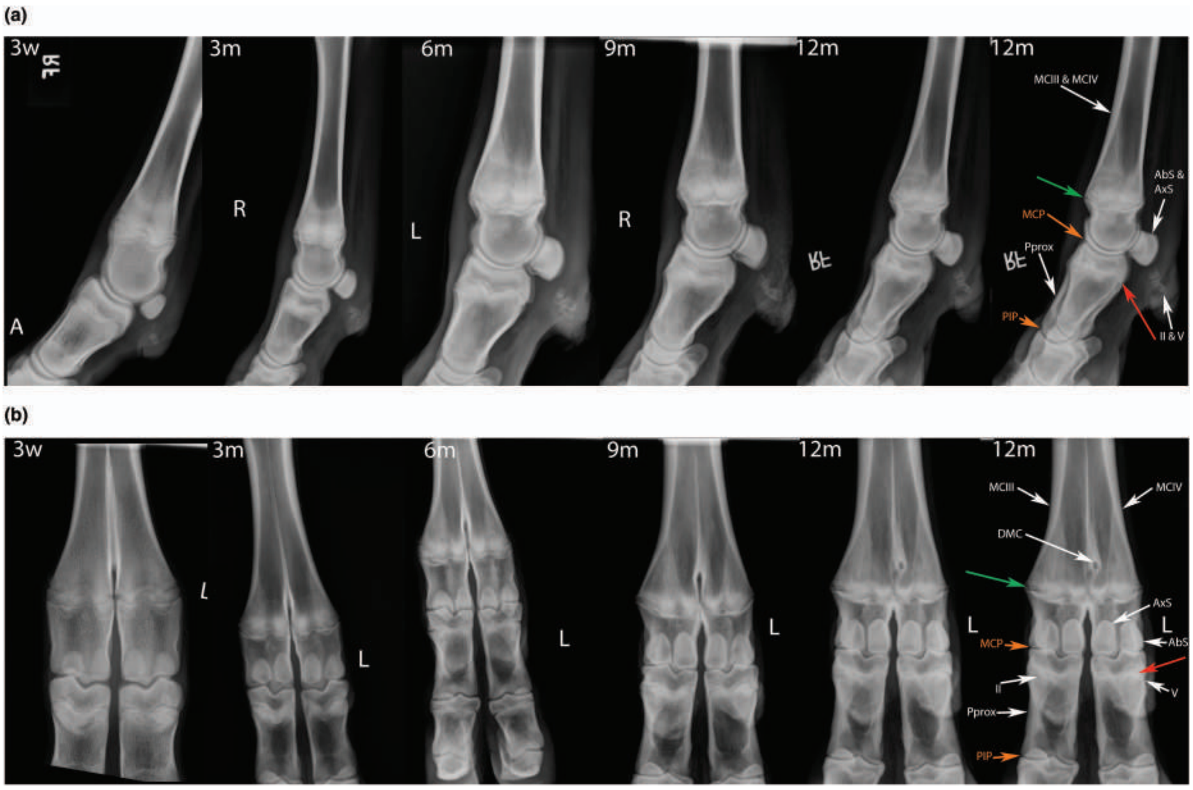

FIG 2: Metacarpophalangeal joint: (a) lateromedial and (b) dorsopalmar views at 3 weeks, 3 months, 6 months, 9 months and 12 months. Green arrow, distal metacarpal physis. Red arrow, proximal phalanx of the proximal phalanx. MCIII, third metacarpal bone; MCIV, fourth metacarpal bone; DMC, distal metacarpal canal; AxS, axial sesamoid bone; AbS, abaxial sesamoid bone; II, second digit; V, fifth digit; Pprox, proximal phalanx; Pmid, middle phalanx; Pdist, distal phalanx; DS, distal sesamoid; MCP, metacarpophalangeal joint; PIP, proximal interphalangeal joint

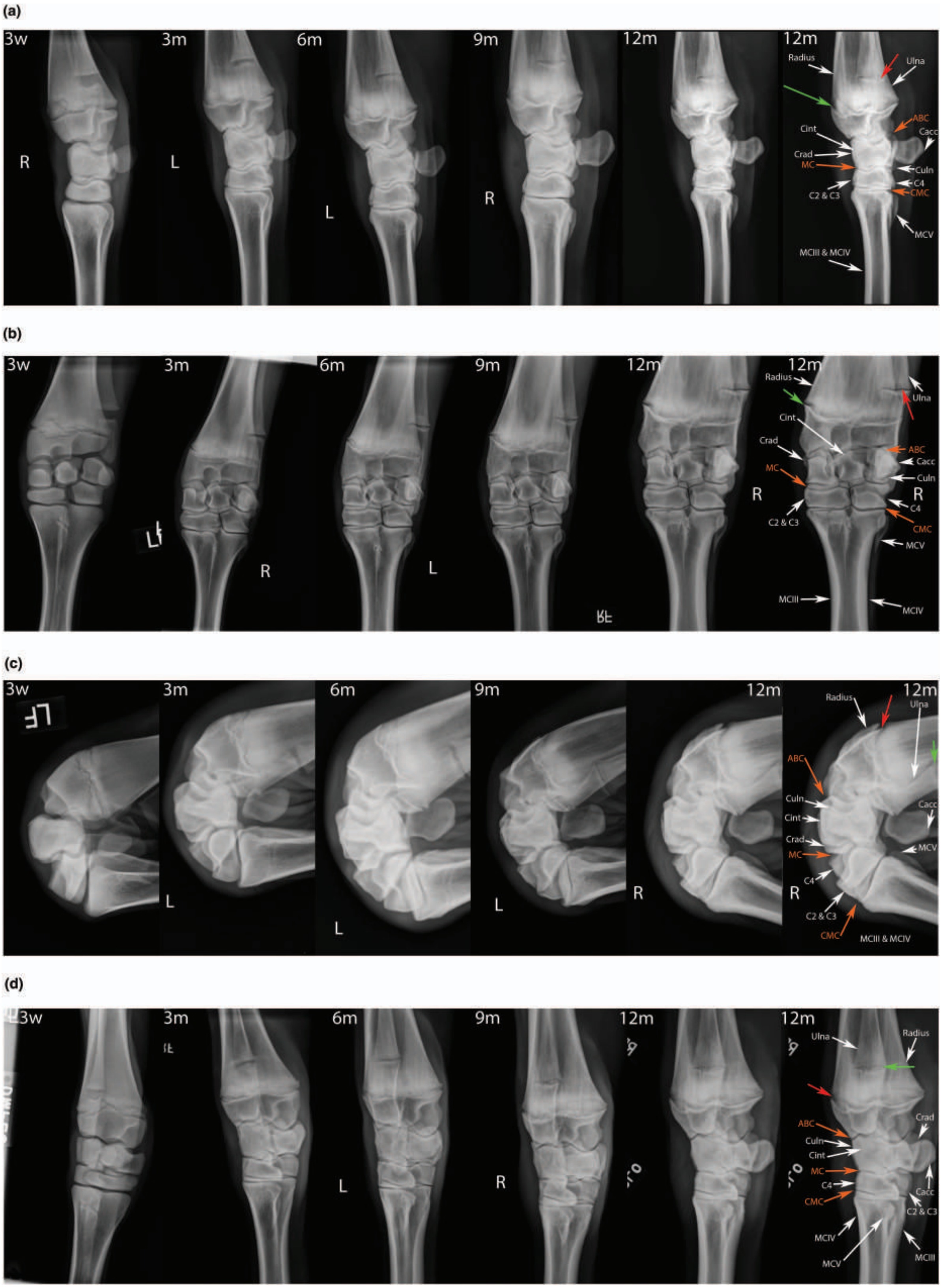

FIG 3: Carpus: (a) lateromedial, (b) dorsopalmar, (c) flexed lateromedial, (d) dorsomedial-palmarolateral oblique, (e) dorsolateral- palmaromedial oblique, (e) dorso35°proximal-dorsodistal oblique and (g) dorso55°proximal-dorsodistal oblique views at 3 weeks, 3 months, 6 months, 9 months and 12 months. Yellow arrow, distal ulnar physis. Red arrow, distal radial physis. Crad, radial carpal bone; Cint, intermediate carpal bone; Culn, ulnar carpal bone; Cacc, accessory carpal bone; C2 and C3, fused second and third carpal bone; C4, fourth carpal bone; MCIII, third metacarpal bone; MCIV, fourth metacarpal bone; MCV, fifth metacarpal bone; ABC, antebrachiocarpal joint; MC, middle carpal joint; CMC, carpometacarpal joint

radiographs at each of the time points clinical history of the subjects was determined and gait observation was performed.

A total of 46 routine views were acquired of all four limbs on-farm using a portable x-ray unit (MinXray HF8015. MinXray, Northbrook, Illinois, USA) and digital radiography system (Sound-Eklin, Carlsbad, California, USA) (table 1). The kV and mili amper seconds (mAs) values were varied depending on the anatomy being imaged. The kV ranges from 72 kV to 80 kV and the mAs values from 0.9 mAs to 4.5 mAs. Radiographs were obtained and quality assessed in a darkened room on-farm.

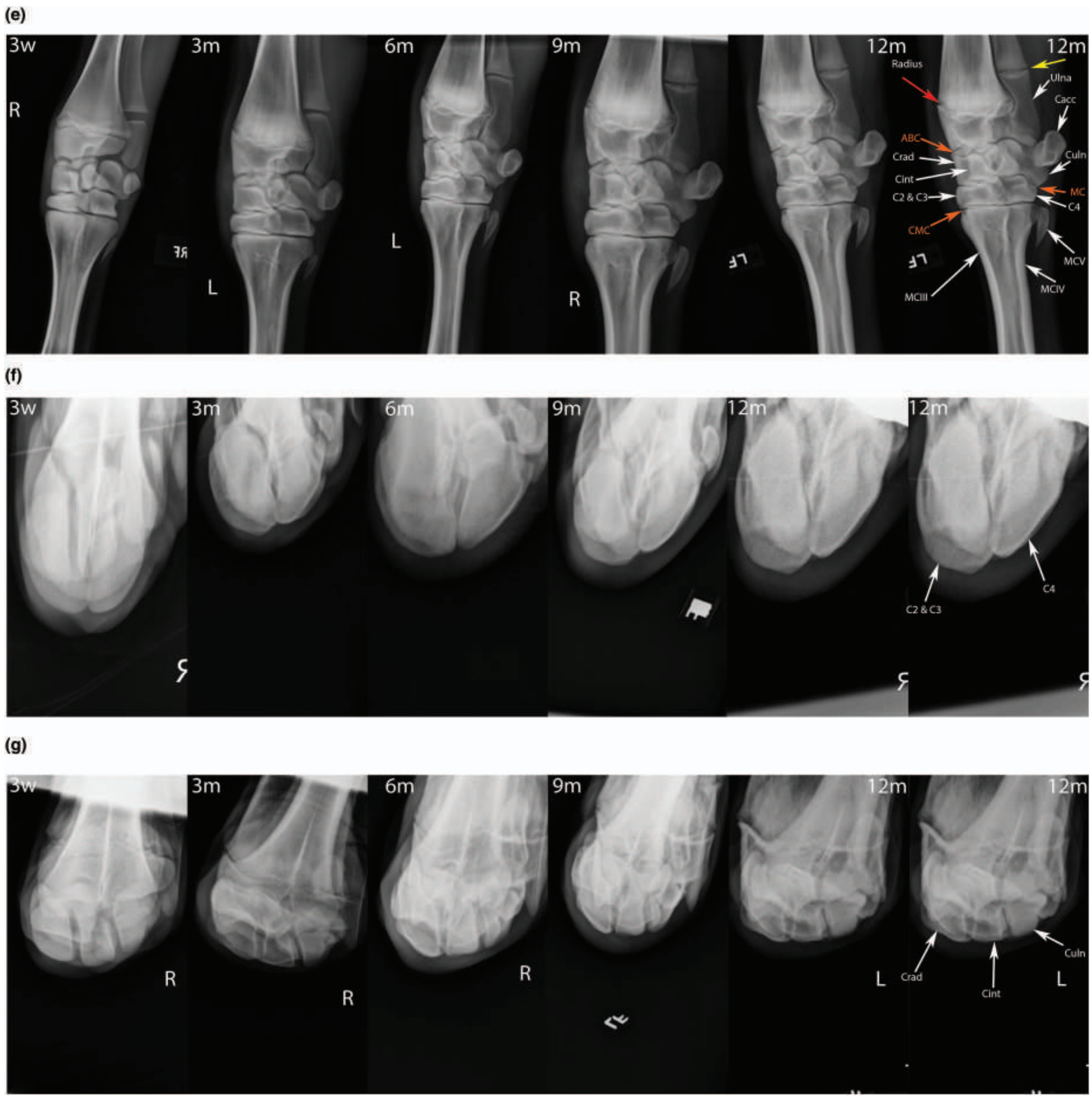

FIG 3: Continued

The images were compiled using Microsoft Powerpoint (Microsoft Powerpoint 2011. Microsoft Corporation, Redmond, Washington, USA) presentations. The images were grouped by subject age. At the end of the study period all radiographs were evaluated by each of the three authors (SEH, RD, MJL), and a representative image of each view was chosen by consensus. Radiographs were evaluated by the authors, for diagnostic quality, presence of artefacts, shape and opacity of bones and joints, margination of the physes/apophyses (including open or closed status). A physis was described as open where there is a distinct radiolucent line spanning the entire extent of the physis. A physis was described as closed where there is no radiolucency in the region of the physis.

Results

Each of the subjects remained clinically normal throughout the study period with no signs of systemic illness or lameness identified. Sedation was not required due to ease of handling in calves less than six months of age. Sedation was administered to the subjects at 9 months and 12 months of age, due to poor compliance and prolonged imaging times. Initial attempts at mediolateral projections of the shoulder at three weeks of age yielded images of adequate quality, but at three months of age images were acquired with a high amount of noise such that the images were of a non-diagnostic quality. As the subjects age, the image quality reduced due to the increased amount of tissue in the primary beam leading to underexposure and increased image noise. This was especially noted with images of the stifle and shoulder. There was increased difficulty of plate placement at the shoulder for caudolateral craniomedial views, keeping the imaging plate perpendicular to the incident beam due to the increased muscle mass. Consequently a total of 44 images was acquired per subject. Each image was deemed of diagnostic quality on-farm. Subsequently the images were imported to the Picture Archiving and Communication System (PACS), further scrutinised and a representative image determined by consensus.

Fore feet

The proximal physes of the proximal and middle phalanges are open at three weeks of age, closing at one year of age (Fig 1). The distal physes of the proximal and middle phalanges are closed at three weeks of age. These physes have a sclerotic margin at six months, with narrowing of the lucent physis between six months and 1 year. The margins of the phalanges are smooth at three weeks of age, becoming well defined at six months of age.

Metacarpophalangeal joints

The distal metacarpal physes remain open throughout the study period. From three weeks to nine months of age, the physeal margins are sharp and well defined, whereas at 12 months of age the physeal margins become more ill-defined (Fig 2). There is mild cranial extension of the dorsal margin of the proximal phalanx at the level of the proximal physis, seen at six months, which becomes smoother by 12 months of age. The rudimentary phalanges of the second and fifth digits are evident at three weeks of age, becoming larger and more well defined by six months.

Carpal joints

The proximal metacarpal physis is closed at three weeks of age. The distal radial and ulnar physes are closed at three weeks of age (Fig 3). The carpal bones are rounded initially, becoming well marginated at three months of age. Initially, at three weeks of age the antebrachiocarpal, middle carpal and carpometacarpal joint spaces are widened. These joint spaces narrow substantially by three months of age and narrow further to a more normal width by six months of age. The fibular head is smoothly well defined with a sharp corticomedullary junction, enlarging from three weeks to six months whereby minimal subsequent enlargement is noted.

Cubital joints

The proximal radial physis is open at three weeks of age, becoming progressively more irregularly marginated, with closed appearance at nine months of age (Fig 4).

The distal humeral physis and the physis of the medial humeral epicondyle are open throughout the study period, with minimal change to the mildly irregular margins. The physis of the ulnar olecranon is widened with smooth margins at three

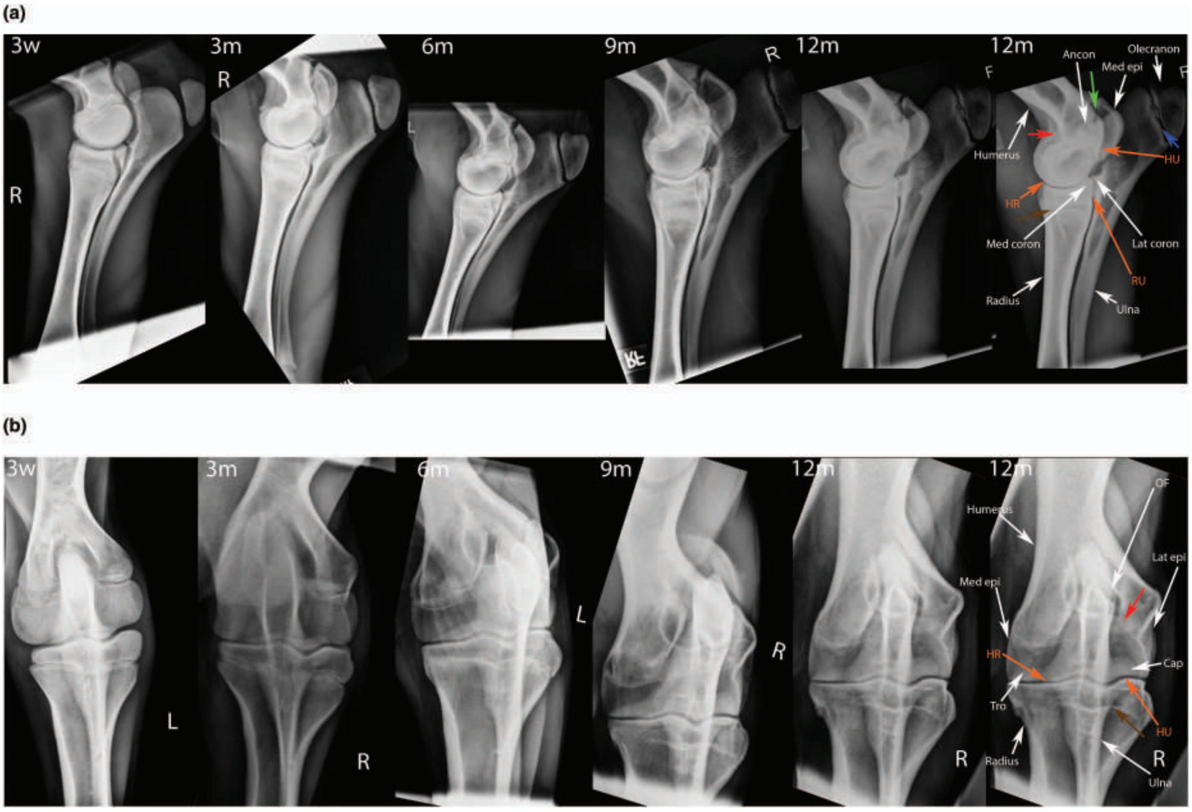

FIG 4: Cubital joint: (a) lateromedial and (b) craniocaudal views at 3 weeks, 3 months, 6 months, 9 months and 12 months. Red arrow, distal radial physis. Brown arrow, proximal radial physis. Blue arrow, physis of the olecranon of the ulna. Lat epi, lateral humeral epicondyle; Med epi, medial humeral epicondyle; Tro, humeral trochlea; Med coron, medial coronoid process of the ulna; Lat coron, lateral coronoid process of the ulna; Cap, humeral capitulum; HU, humeroulnar joint; HR, humeroradial joint; RU, radioulnar joint

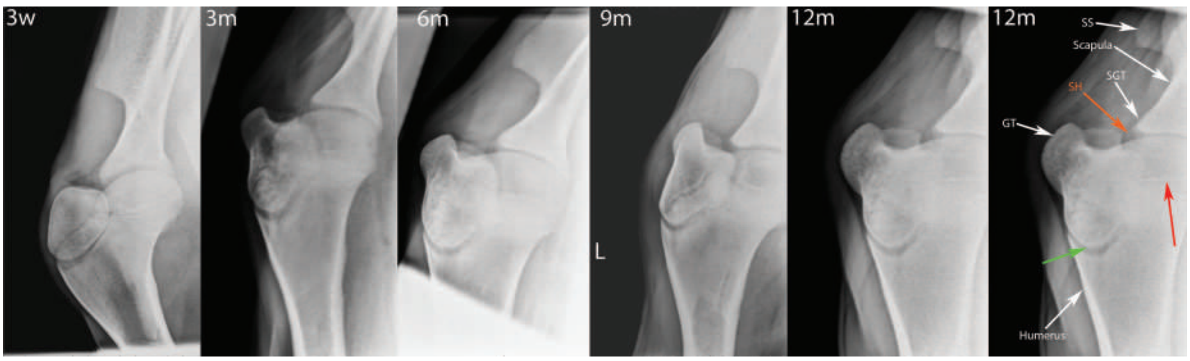

FIG 5: Shoulder: caudolateral-craniomedial views at 3 weeks, 3 months, 6 months, 9 months and 12 months. Red arrow, physis of the humeral head. Green arrow, physis of the greater tubercle of the humerus. SS, scapular spine; SGT, supraglenoid tubercle; GT, greater tubercle; SH, scapulohumeral joint

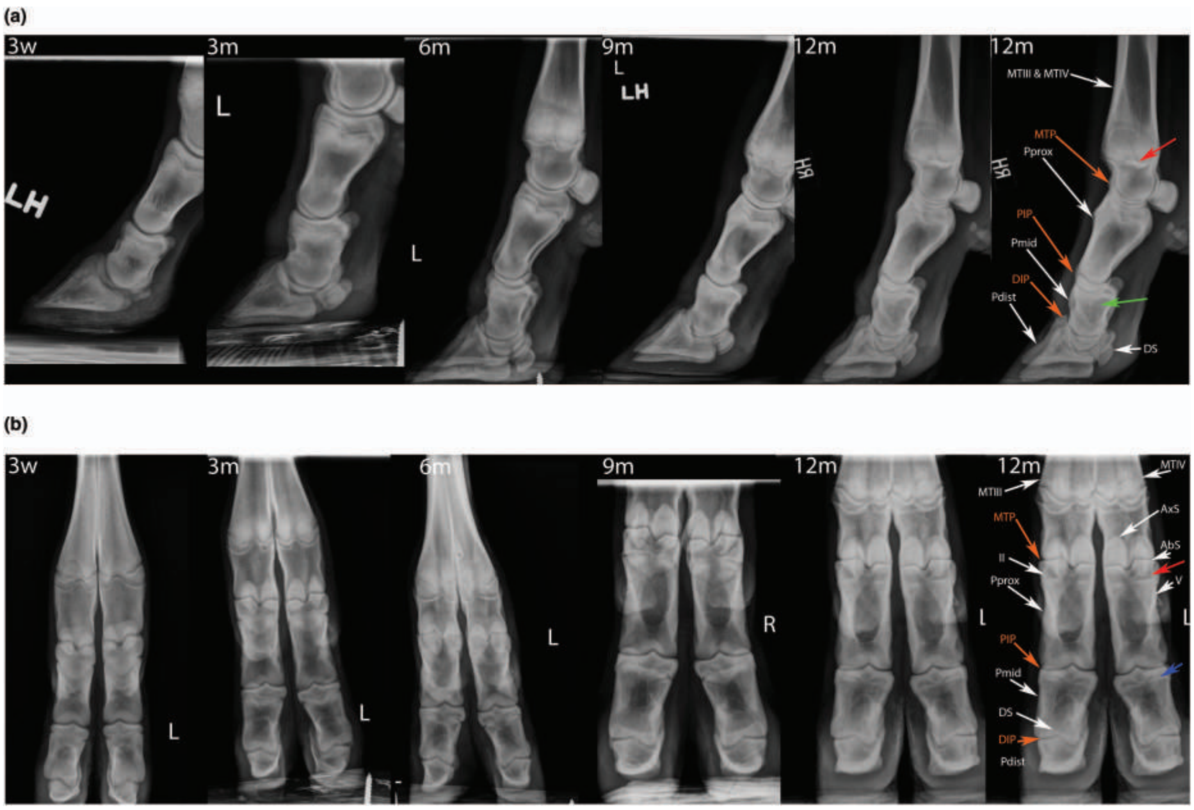

FIG 6: Hind foot: (a) lateromedial and (b) dorsoplantar views at 3 weeks, 3 months, 6 months, 9 months and 12 months. Red arrow, proximal phalanx of the proximal phalanx. Blue arrow, proximal physis of the middle phalanx. MTIII, third metatarsal bone; MTIV, fourth metatarsal bone; AxS, axial sesamoid bone; AbS, abaxial sesamoid bone; II, second digit; V, fifth digit; Pprox, proximal phalanx; Pmid, middle phalanx; Pdist, distal phalanx; DS, distal sesamoid; MTP, metatarsophalangeal joint; PIP, proximal interphalangeal joint; DIP, distal interphalangeal joint

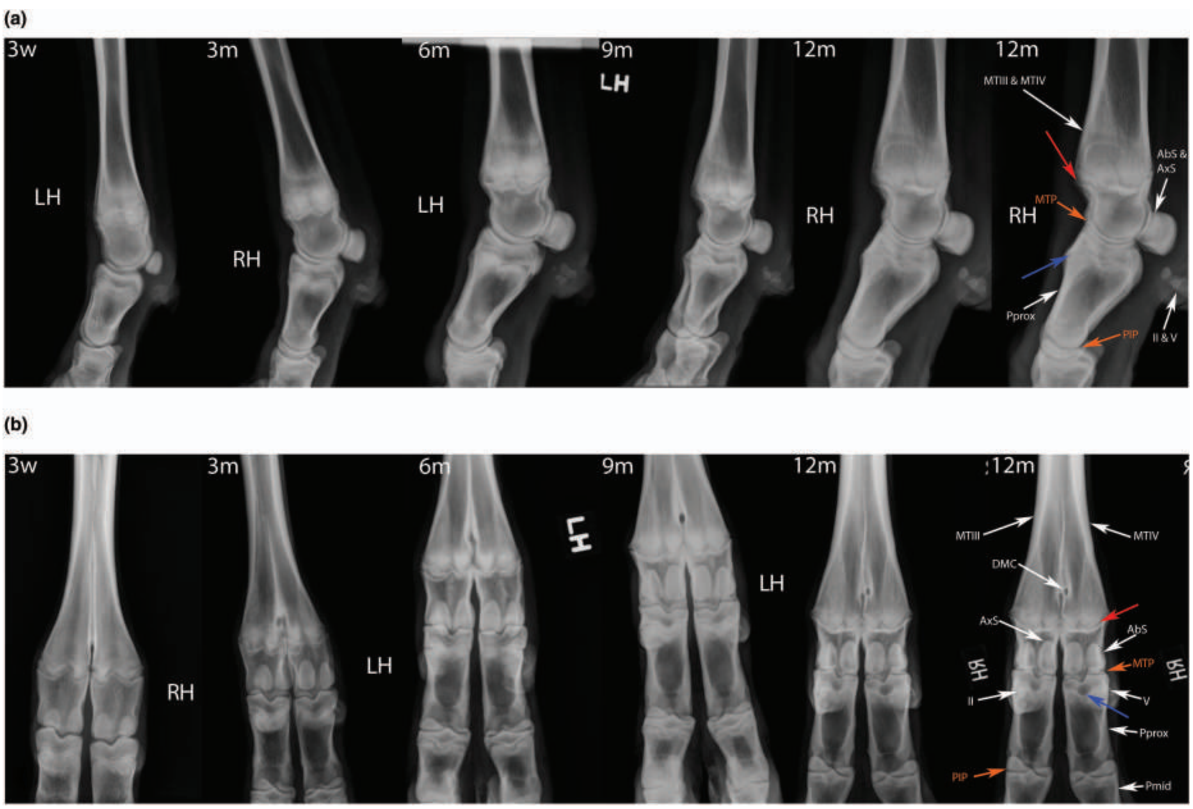

FIG 7: Metatarsophalangeal joint: (a) lateromedial and (b) dorsoplantar views at 3 weeks, 3 months, 6 months, 9 months and 12 months. Red arrow, distal metatarsal physis. Blue arrow, proximal phalanx of the proximal phalanx. MTIII, third metatarsal bone; MTIV, fourth metatarsal bone; DMC, distal metatarsal canal; AxS, axial sesamoid bone; AbS, abaxial sesamoid bone; II, second digit; V, fifth digit; Pprox, proximal phalanx; Pmid, middle phalanx; MTP, metatarsophalangeal joint; PIP, proximal interphalangeal joint

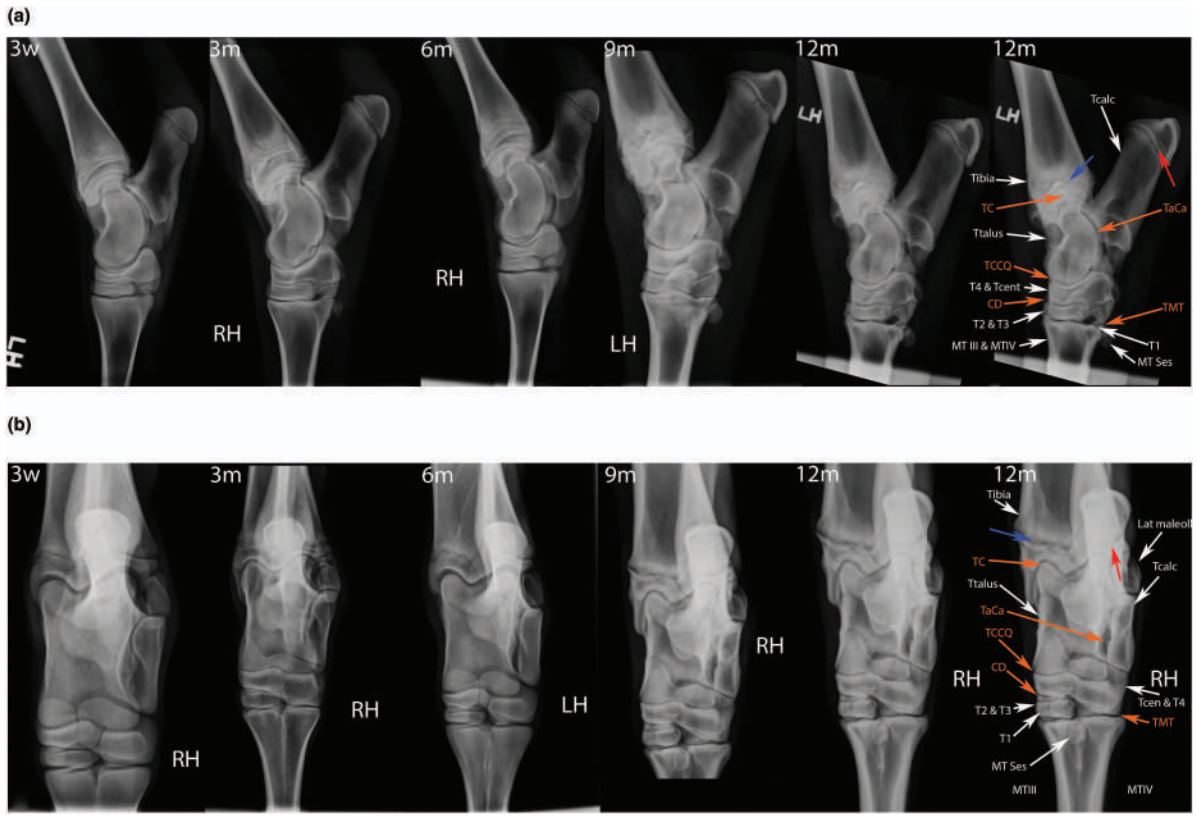

FIG 8: Tarsus: (a) lateromedial, (b) dorsoplantar, (c) dorsomedial-plantarolateral oblique, (d) dorsolateral-plantaromedial oblique and (e) plantaroproximal-plantarodistal oblique views at 3 weeks, 3 months, 6 months, 9 months and 12 months. Blue arrow, distal tibial physis. Red arrow, physis of the tuber calcaneus. Ttalus, talus; SusTal, sustentaculum talus; Tcalc, calcaneus; Tcen and T4, fused central and fourth tarsal bone; T2 and T3, fused second and third tarsal bones; T1, first tarsal bone; MT ses, metatarsal sesamoid bone; MTIII, third metatarsal bone; MTIV, fourth metatarsal bone; TC, tarsocrural joint; TaCa, talocalcaneal joint; TCCQ, talocalcaneal-centroquartal joint; CD, centrodistal joint; TMT, tarsometatarsal joint

weeks of age. These margins become more irregular over time, with mild mineralised bridging of the physeal gap at 12 months of age. The articular margins of the radius, ulna and humerus are rounded at three weeks of age becoming better defined by six months of age and remaining similar over the remainder of the study period.

Scapulohumeral joints

The distal scapular physis, and the cranial glenoid physis are closed at three weeks of age (Fig 5). The apophysis of the scapular supraglenoid tubercle superimposes the distal scapula at all times. The proximal humeral physis is closed at 12 months of age. The separate centre of ossification of the greater tubercle remains distinct throughout the study, and the separate centre of ossification of the lesser tubercle of the humerus is indistinct from the greater tubercle at three months of age. The articular margins of the glenoid rim and humeral head is smooth at three weeks of age, with sharper margins at three months of age.

Hind feet

The proximal physis of the middle phalanx is open at three weeks of age, the margins of the physis becoming mildly irregular at six months of age and closing by nine months of age (Fig 6). The proximal physis of the proximal phalanx becomes mildly irregular at nine months and is closed at 12 months of age. The distal physes of the proximal and middle phalanges are closed at three weeks of age. The phalangeal margins are smooth at three weeks, becoming well defined at six months of age. Initially at three weeks the interphalangeal joints are mildly wide becoming normal width at six months of age.

Metatarsophalangeal joints

The distal metatarsal physes remain open throughout the study period, with mild irregularity of the physis at six months of age progressing to moderate irregularity at 12 months of age (Fig 7). The rudimentary phalanges of the second and fifth digits are small and smoothly marginated at three weeks of age, becoming more well defined and larger by six months of age, similar to the forelimb. Similar to the forelimb, but to a lesser extent, there is mild cranial extension of the dorsal margin of the proximal phalanx at the level of the proximal physis, seen at 6 months, which becomes smoother by 12 months of age.

Tarsal joints

The distal tibial physis is open at three weeks and three months of age, becoming mildly irregular at six months of age with moderate irregular margination at 12 months of age (Fig 8). The lateral maleolar physis is sharply marginated throughout the study period, with moderate narrowing of the physis between 6 months and 12 months of age. The tuber calcaneal apophysis is sharply marginated at three weeks to six months of age, with mild irregularity at 9 months and 12 months of age. The tarsal bones are rounded and small in size at three weeks of age, with wide intertarsal joints. At three months of age the margins of the tarsal bones are more cuboidal in shape with narrowing of the intertarsal joints, which are a normal width by six months. A lucent line is present between the separate centres of ossification of the fourth and central tarsal bones, which narrows from three weeks of age, leading to fusion of the fourth and central tarsal bones at nine months of age. The fibular head is small in size with well defined margins, becoming larger over time. The lateromedial projection of the tarsus required a mild deviation of the incident beam 10° in a proximodistal direction to adequately

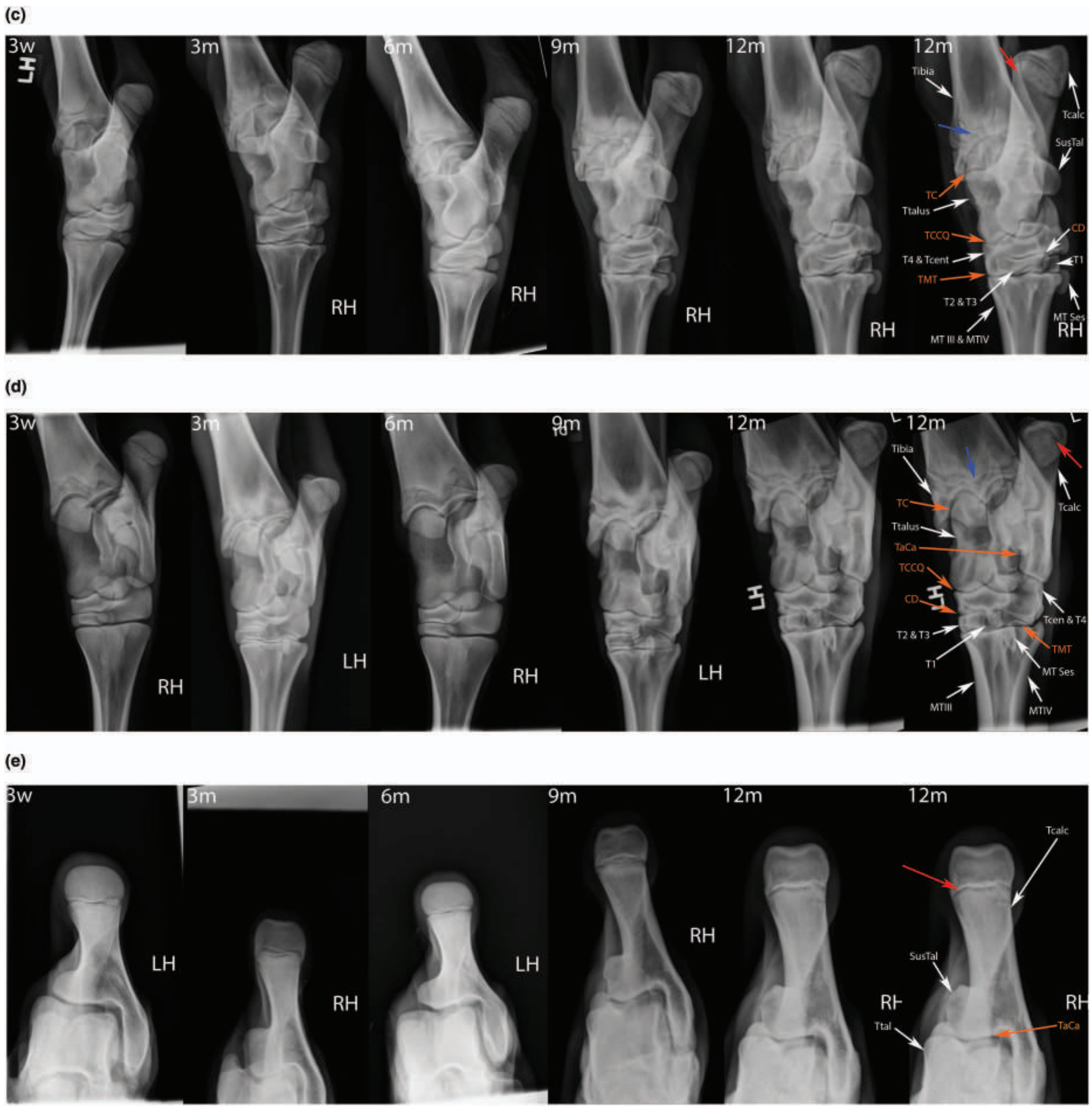

FIG 8: Continued

highlight the tarsal joints, as there was some superimposition on initial pure lateromedial projection.

Stifle joints

The patella is initially small in size and semicircular in shape, with mild undulation of the proximal margin (Fig 9). There is progressive proximodistal lengthening to a teardrop shape between three weeks and nine months of age. Mild irregular margination of the proximal tibial physis was seen at three months of age, with moderate irregular margination at 9 months and 12 months of age. Mild irregularity of the physeal line between the tibial tuberosity and the tibial proximal epiphysis and the proximal metaphysis was noted throughout the study. The caudocranial view required a mild deviation of the incident beam by 10° proximodistally, to adequately highlight the femorotibial joint and reduce superimposition.

In one patient, there are regions of coalescing geographical lucency with a rim of sclerosis within the central to lateral aspects of the distal metaphysis of the right and left tibia, and the central aspects of the right and left distal metaphysis of the metatarsal bones (Fig 10). These regions of lucency are no longer present at three months of age. The remainder of the subjects was normal and changes to the appendicular skeleton over time were consistent in the cohort.

Discussion

In radiographic assessment the recognition of normalcy is paramount in the detection of abnormalities and disease. The possibility of image acquisition using a portable x-ray tube and detector, which are becoming more and more common in equine and mixed practice, mean that these images can be acquired as part of the clinical workup of the patient. In clinical and academic practice these images acquired can allow detection of pathological changes, such as joint space widening, irregular margination of physes and the normal appearance of separate centres of ossifications.

The normal radiographic anatomy of the juvenile bovine limb from three weeks to one year of age is depicted. The radiographic findings of three of the four subjects were similar throughout the study, with a comparable appearance of each of the individual physes during the 12 month study period.

Image acquisition on-farm was simple with the portable x-ray tube and direct radiography imaging plate. Quality control was simultaneous and repeat images could be performed where images were of questionable quality. When the images were transferred to PACS and imaged on medical grade monitors, some inadvertent superimposition was detected in some images. Radiographs of the stifle and shoulder regions were underexposed in many cases, due to the limitations of the handheld x-ray tube.

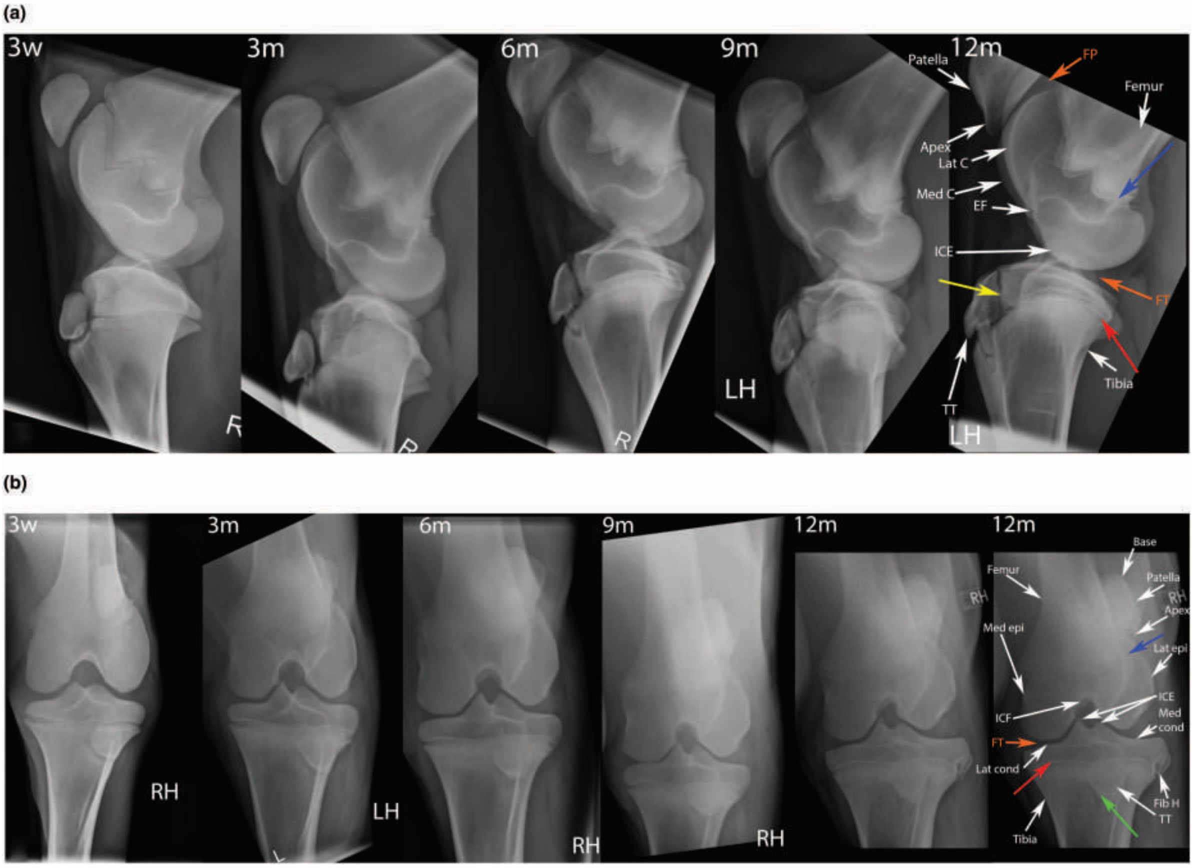

FIG 9: Stifle: (a) lateromedial and (b) caudocranial views at 3 weeks, 3 months, 6 months, 9 months and 12 months. Blue arrow, distal femoral physis. Red arrow, proximal tibial physis. Yellow arrow, physis of the tibial tuberosity. Lat C, lateral femoral condyle; Med C, medial femoral condyle; Med epi, medial epicondyle of the tibia; EF, extensor fossa; Lat epi, lateral epicondyle of the tibia; Lat cond, lateral tibial condyle; Med cond, medial tibial condyle; ICE, intercondylar eminence; Fib H, fibular head; TT, tibial tuberosity

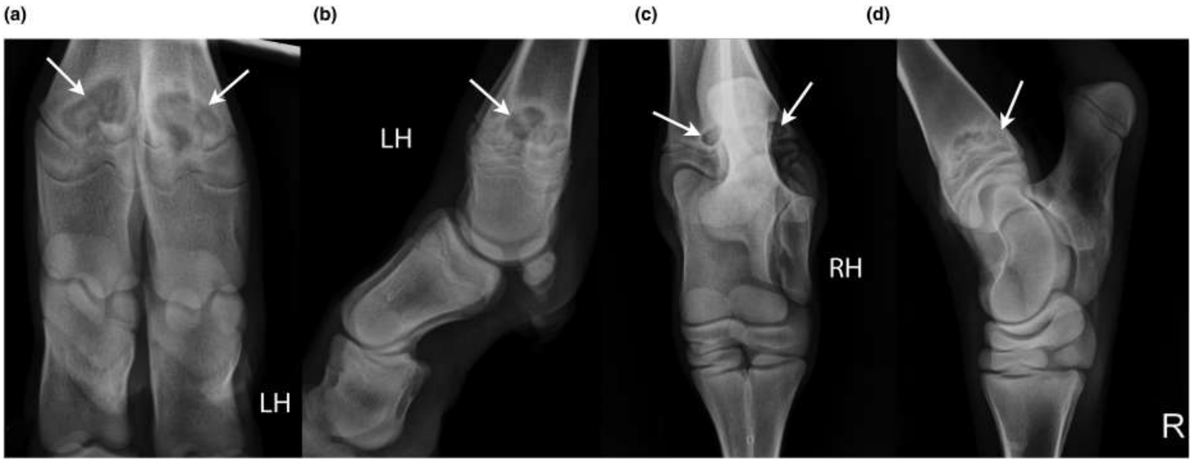

FIG 10: Right metacarpophalangeal joint (a) dorsoplantar and (b) lateromedial views and left tarsus (c) dorsoplantar and (d) lateromedial views. Well defined coalescing geographic lucency and thin rim of sclerosis at the distal metaphysis of the left tibia, and the left distal metaphysis of the metatarsal bones (arrows)

The use of a higher output x-ray tube in the hospital setting would allow penetration of these tissues with less noise. Similarly radiographic quality assessment using higher resolution monitors may allow detection of imperfections which were not identified on-farm.

It was notable that in one of the subjects, there were lucent cyst-like structures in the region of the distal tibial and metatarsal physes at three weeks of age, which resolved by three months of age indicating a probable benign nature of the lesions. With progressive endochondral ossification occurring within the physes with an ultimately normal radiographic appearance, the authors suggest that these lucencies represent a region of delayed mineralisation and ossification. Further differentials for these structures include osteochondritis, and unlikely aneurysmal bone cysts, fibrous dysplasia or osteomyelitis (Smallwood and Shively 1981, Wilson 1989, Wrigley 2000).

The normalcy of the subjects could not be confirmed with postmortem examination, as the animals are part of a commercial dairy herd and clinical history and gait observation was used to confirm normalcy. Comparison of the results of this study to radiographs of juvenile bovine patients with a clinical history of gait alteration or lameness will be helpful to describe the effect of specific diseases on the alteration of the juvenile skeleton over time. To the best of the authors' knowledge and despite a comprehensive literature search, there is no peer-reviewed reference available for physeal closure times in cattle.

This study should serve as a reference and aid in the detection of abnormalities, with additional studies warranted to further evaluate the progressive changes in the appearance of the physes over time.

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