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Canine tarsal architecture as revealed by high-resolution computed tomography

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ABSTRACT

Central tarsal bone (CTB) fractures are well documented and are a subject of increasing importance in human, equine and canine athletes although the mechanism of these fractures in dogs is not fully understood and an extrapolation from human medicine may not be accurate. This study reports the use of high-resolution computed tomography (CT) of 91 tarsal joints from 47 dogs to generate a more detailed *in situ* anatomical description of the CTB architecture in order to obtain a better understanding of the pathogenesis of CTB fractures in this species. The dogs studied represented a wide range of ages, breeds and levels of habitual physical activity and the angles of the tarsal joints studied ranged between maximal flexion (16.4°) and maximal extension (159.1°).

Regardless of tarsal angle, the CTB articulated with the calcaneus exclusively at the level of its plantar process (PP_{CTB}) in all dogs. The PP_{CTB} presented two distinct parts in all dogs, a head and a neck. The calcaneus tended to rely on the PP_{CTB} neck during flexion and on the PP_{CTB} head during extension. This study describes new tarsal elements for the first time, including the calcaneal articular process, the fourth tarsal bone plantar articular process and the talar plantar prominence of the CTB. Based on calcaneo-PP_{CTB} architecture, it is postulated that the PP_{CTB} is a keystone structure and that at least some of CTB fractures in dogs could either commence at or are induced at this level due to the impingement forces exercised by the calcaneus.

Introduction

The tarsal joint is a complex articulation that requires a detailed anatomical depiction. The literature provides plentiful records about the body of the navicular, or central tarsal bone (CTB) in dogs (Berg, 1982; Dobberstein and Hoffmann, 1961; Ghetie, 1971; Koch, 1960; Koch and Berg, 1985; Martin, 1923; Nickel et al., 1992), but there is a dearth of data regarding its medial and plantar processes (Evans, 1993; Ghetie, 1971; Nickel et al., 1961).

Even more puzzling is the information about CTB articulations. While it is generally held that the CTB articulates with all the other six tarsal bones (Guilliard, 2000; Muir et al., 1999; Vaughan, 1987), the calcaneus is often not mentioned when its articular surfaces are described. The CTB is described as articulating with the talus proximally, the fourth tarsal bone laterally and the first, second and third tarsal bones distally (Berg, 1982; Dobberstein and Hoffmann, 1961; Ghetie, 1971; Koch, 1960; Koch and Berg, 1985; Martin, 1923; Nickel et al., 1992). Paradoxically, some authors mention an articular facet with the CTB when describing the calcaneus, but this has been omitted in the description of the CTB (Koch, 1960; Koch and Berg, 1985; Nickel et al., 1992). The only reports we were able to find that mentioned a CTB articular surface for the calcaneus are also contradictory regarding its location proximally (Evans, 1993; Guilliard, 2007; Sajjarengpong et al., 2000) vs. laterally (Bergh, 2008).

Nevertheless, it is generally accepted (Gielen et al., 2001) that a thorough knowledge of tarsal anatomy and the relationships between its component bones is essential for understanding the pathogenesis of tarsal injuries. Such injuries, with a strategic place and major role occupied by the CTB, are well described in human (Brukner et al., 1996; Eichenholtz and Levine, 1964) and veterinary (Bergh, 2008; Boudrieau et al., 1984) medicine, and have been the subject of considerable investigation. However, the exact mechanism of the different CTB fracture types in dogs is not fully understood. There are a number of questions remaining.

Firstly, is there really a trend for racing dogs to fracture the body of the CTB (Bergh, 2008; Boudrieau et al., 1984; Devas, 1961; Jones, 2009; Piras and Johnson, 2006), since the main presentation in the few reported cases of non-racing dogs is fracture/avulsion of the plantar process of the CTB (PP_{CTB}) (Guilliard, 2007; Harasen, 1999; Hay et al., 1995; Johnson et al., 2000; Lorinson and Grösslinger, 2001; Muir et al., 1999; Piermattei et al.,

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2006; Vaughan, 1987)? Additionally, why are there so few fractures of the left CTB in racing Greyhounds (4% of all CTB fractures; Boudrieau et al., 1984), despite the fact that when engaging a counterclockwise bend at full speed, and under centripetal acceleration, the left tarsal region withstands the full effective bodyweight (Piras and Johnson, 2006)?

These questions could indicate that an extrapolation of the mechanism of CTB fractures from plantigrade humans to digitigrade dogs might not always be straightforward due to the different anatomical and functional architecture of the foot. Furthermore, extending our understanding of the CTB articular configuration at different tarsal angles might throw more light on the pathogenesis of tarsal fractures. These fractures are represented by fracture-avulsion of the PP_{CTB} in non-racing dogs and catastrophic injuries in racing dogs, and are considered an important welfare concern. Aiming to elucidate the spatial relationship of the calcaneo-central articulation, we hypothesized that there is no contact between the calcaneus and the body of the CTB at any tarsal angle, the only area were these two bones are juxtaposed being at the level of PP_{CTB}.

The aim of this study was to generate a detailed *in situ* anatomical description of the CTB architecture, to gain a better understanding of the pathogenesis of CTB fractures, using high-resolution computed tomographic (CT) images of canine tarsal joints.

Materials and methods

Dogs

Forty-seven dogs, including 41 dogs of 28 different breeds and six mixed-breed dogs, were analysed in this retrospective study. There were 27 males and 20 females. Age ranged between 9 months and 14 years. Of the four German Shepherd dogs included in the study, two were active working police dogs, one was a dog that participated in agility competitions and one was a non-working and non-athletic dog. All but two dogs had no known orthopaedic diseases. A German Shepherd dog had evidence of cortical fracture and sclerosis of the PP_{CTB} at the level of its articulation with calcaneus (right hindlimb) and a Doberman presented sclerotic changes at the level of distal tibia and fibula, proximal talus and sustentaculum tali (left hindlimb). The dogs were classified into two main groups, namely, (a) small dogs (adult bodyweight ⩽10 kg) and (b) medium and large dogs (adult bodyweight >10 kg).

Computed tomographic data acquisition and imaging

Computed tomographic (CT) data were acquired using a third-generation, 128-slice scanner (Aquilion CX, Toshiba Medical Systems). Settings for the CT helical scan protocol were 120 kV, 100–300 mA, and 0.5 mm acquisition slice thickness. The reconstruction protocol included both body-standard and bone-high resolution algorithms with a reconstruction slice thickness/slice interval of both 1/0.8 mm and 0.5/0.25 mm.

ViTREA 2 version 4.0 medical imaging software (Vital Images) was used for two-(2D) and three-dimensional (3D) analysis of CT images. We used volume-rendering software, simultaneous imaging of specific anatomical structures of interest using a combination of 2D orthogonal multi-planar reconstructions (MPR) and 3D images, trim function with 3D and 2D segmentation to focus images on regions of interest, a wide variety of clinical viewing protocols and fine adjustment of visualisation parameters so as to enhance diagnostic quality images. Oblique and curved MPRs were necessary in order to delineate several structures with a complex 3D architecture.

Study design

High resolution CT images of 91 tarsal joints from the 47 dogs were analysed in this retrospective study (Table 1). For the purposes of comparison, both left and right tarsal joints were analysed in 44 dogs. For each tarsal joint, the following anatomical features were studied and compared between dogs: general tarsal architecture (particularly the position, shape, orientation, and cortical aspect of the PP_{CTB}) and the location of the contact surface between the calcaneus and CTB (Fig. 1).

The position of the calcaneus and the PP_{CTB} with respect to the CTB was defined in two ways for each tarsal joint, namely (1) 2D analysis of orthogonal and oblique MPRs and (2) advanced CT 3D evaluation by means of complex visualisation tools including volume rendering, oblique trim in 3D and segmented 3D reconstructions.

Table 1
Breeds and numbers of dogs included.

	Small dogs (adult bodyweight ⩽10 kg)	Medium and large dogs (adult bodyweight >10 kg)
	Bolonka Zwetna, Chihuahua, Italian Greyhound, Jack Russell Terrier, Maltese, Miniature Pinscher, Poodle (Toy and Miniature), Prague Ratter, Pug, and Yorkshire Terrier	Akita Inu, Beagle, Boxer, Bouvier des Flandres, Bull Terrier, Dachshund, Doberman, Dog De Bordeaux, German Shepherd, Golden Retriever, Hanoverian hound, Labrador, Munsterlander, Norwegian Elkhound, Poodle (Standard), Rottweiler, Schnauzer, and Welsh Terrier
	Two mixed breed 14 Pure breed	Four mixed breed 27 Pure breed
Breeds (*n*)	10	18
Dogs (*n*)	16	31

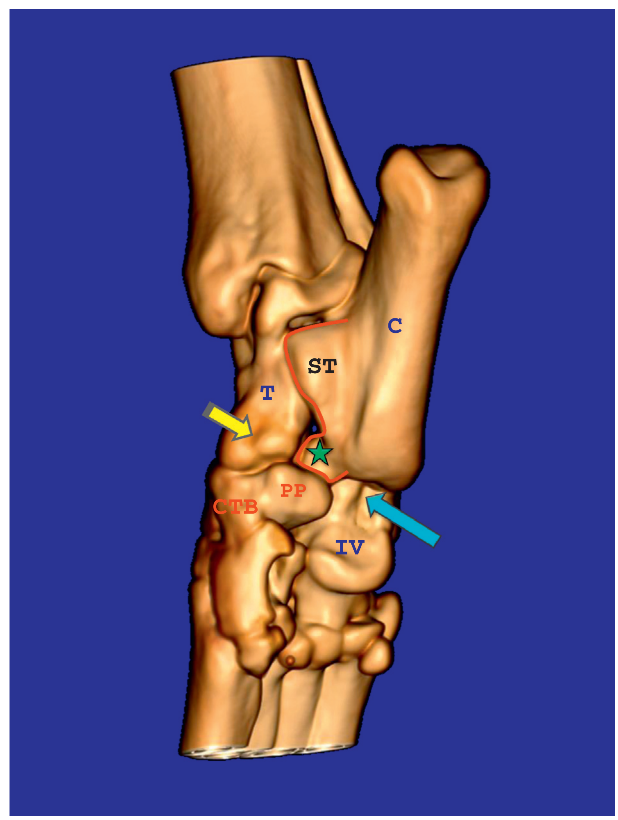

Fig. 1. Novel tarsal elements. Quartal (IV) plantar articular process for central tarsal bone (CTB; long arrow), talar (T) plantar tubercle (short arrow) and calcaneal (C) articular process for CTB, respectively PP_{CTB} (PP; star). The half-butterfly shape of the calcaneus is traced with a large, proximal wing represented by the sustentaculum tali (ST) and a small, distal wing corresponding to the calcaneal articular process for CTB (star).

Tarsal joint angles were measured on CT images in the sagittal projection obtained through the calcaneal coracoid process, and were established as the angle between the tibia (longitudinal midline) and the calcaneus (longitudinal midline) (Fig. 2A–C).

Statistical analysis

Statistical analysis was performed with PASW Statistics 18.0.0 (IBM Corporation) software. Two-step cluster and discriminant tests were used to evaluate the relationship between bodyweight and lobulation of the PP_{CTB} head. Differences were considered statistically significant when $P < 0.05$.