Anatomical and pathophysiological features and treatment of elbow luxation in rabbits

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Key words

Rabbit, elbow luxation, elbow anatomy, computed tomography, osteoabsorptiometry

Summary

Objective: Functional anatomical evaluation of elbow luxation in rabbits and comparison of this lesion in rabbits, cats and dogs. **Materials and methods:** The relative frequency of elbow luxation and the most common direction of antebrachial bone dislocation in rabbits were compared catamnestically with data in dogs and cats. Goniometric evaluation of the range of motion of the elbow was carried out in 14 rabbits. This was followed by visualisation of the anatomical structures of cadaver elbows and measurement of the subchondral bone density of the elbow using computed tomographic osteoabsorptiometry in seven rabbits and seven cats. Finally, stabilisation of the elbow joint using wire to replace the collateral ligaments was evaluated in cadaver specimens. **Results:** Rabbits undergo elbow luxation approximately four times more often than cats and dogs. Caudal elbow luxation is most commonly seen in rabbits. The elbow functions as a "snap joint" because of the eccentric origin of the collateral ligaments, and has good lateral stability, which is afforded by a sagittal crest of the humeral condyle. Computed tomographic osteoabsorptiometry showed that the caudal region of the elbow joint undergoes the most mechanical stress. **Conclusions and clinical relevance:** The anatomical structure of the elbow of rabbits allows primarily sagittal movement; excessive force poses a risk of injury to the cranial aspect of the joint capsule and the humeroulnar ligaments. When closed reduction and a Velpeau sling do not provide stabilisation for the treatment of elbow luxation, transosseus replacement of the humeroulnar collateral ligaments may be indicated.

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Introduction

The function of the elbow joint is closely related to species-specific mobility requirements. In domestic mammals, the elbow consists of the humeroradial and humeroulnar joints, which are within a common joint capsule. The proximal connection between the radius and ulna, which allows joint rotation, is also included in the joint capsule. The bony structures of the elbow of rabbits are considered to correspond to those of dogs and cats (12), although to the authors' knowledge, comparative studies have not been done.

The collateral ligaments of the feline elbow consist of a long narrow crus extending to the radius and a shorter thicker crus to the ulna (▶Fig. 1). The ulnar crura are under constant tension with movement of the elbow joint, whereas the radial crus is relaxed during flexion. This position provides the radius with a large range of rotation. In contrast, the lateral collateral ligament of dogs consists of a strong radial component and a weaker ulnar component. The opposite is true for the medial collateral ligament, which results in limited rotational movement in dogs (19). The elbow joint functions as a hinge joint, which allows flexion and extension in the sagittal plane. In dogs, the elbow also functions as a „snap joint" because of the eccentric origin of the collateral ligaments on the humerus (11). The nature of the collateral ligaments and the anchoring of the anconeal process in the olecranon fossa results in a species-specific limitation in lateral movement (1, 17). The total range of elbow rotation is markedly smaller in dogs (15) than in cats (19).

Because there is little information on the functional anatomy and biomechanical characteristics of the elbow joint of rabbits, the purpose of this study was to investigate species-specific differences between rabbit and carnivores (cats and dogs) with respect to elbow function and anatomy. These comparisons may help us understand why elbow luxation is the most common luxation in the rabbit, whereas hip luxation is the most common luxation in dogs and cats (20). Elbow luxation is most often lateral or caudal in cats and mainly lateral in dogs (1, 15, 20).

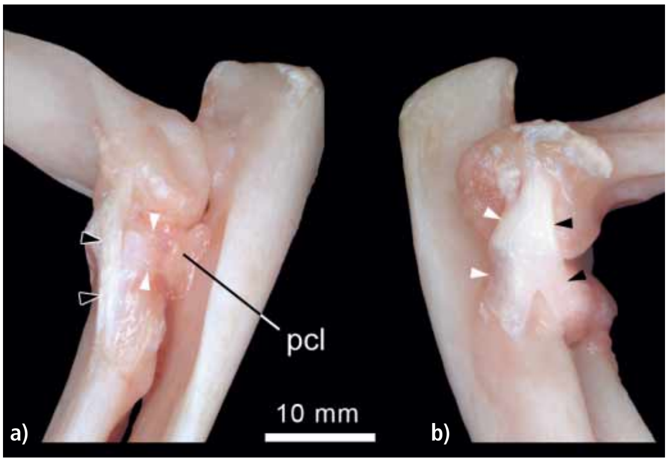

Fig. 1 Left elbow joint of a 3.5-kg cat: a) Lateral view, b) Medial view. The collateral ligaments consist of a radial (black arrowhead) and a ulnar crus (white arrowhead). The ulnar crus of the lateral collateral ligament attaches broadly on the lateral coronoid process.

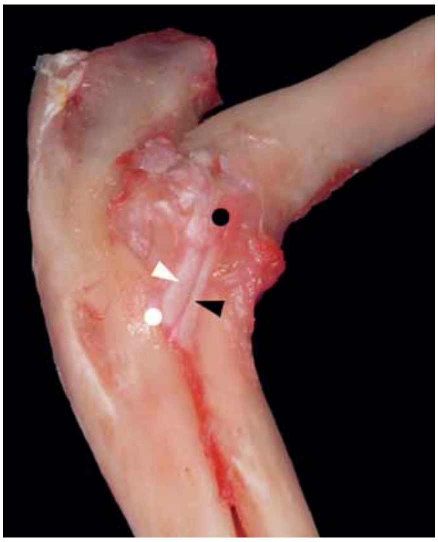

Fig. 2 Medial view of a rabbit elbow showing the medial collateral ligament (white arrowhead: stronger ulnar crus; black arrowhead: radial crus) and the drilled holes in the humerus (black circle) and ulna (white circle) for stabilization of caudal elbow luxation.

A method using computed tomographic osteoabsorptiometry (CTOAM) was developed by Müller-Gerbl (9) to measure bone density and evaluate load distribution within a joint. It was used to visualize the distribution of load in the surface of subchondral bone, which acts as a shock absorber to protect the overlying cartilage from excessive axial force (14). The thickness of subchondral bone varies from joint to joint as well as within a joint (10). Areas of mineralization are determined by the joint load history; regions of the joint surface that undergo more load have increased mineralization and thicker subchondral bone than areas with less load, in which there is a loss of mineralization (9). The duration of loading plays a more important role in this process than the magnitude of the load.

The goal of the present study was to compare the anatomical characteristics of the elbow joint of rabbits, cats and dogs using postmortem preparations, which included the bones, ligaments and musculature of the elbow, as well as subchondral bone density measurements obtained by computed tomography. The frequencies of elbow luxation were compared in these three species catamnestically and analysed in relation to hip luxation, which is the most common luxation in dogs and cats. Based on the results of the anatomical findings and the direction of elbow luxation, a stabilization method for recurrent elbow luxation in rabbits was investigated.

Materials and methods

The overlying skin and subcutaneous tissues were removed from the forelimbs of seven rabbits to expose the muscles, ligaments and bones of the elbow. The range of motion of the elbow was measured using a commercial goniometer (Sport-Tec, 15 cm arm length) in seven euthanized and seven live rabbits (28 elbow joints). The angle of the elbow joint was measured with the animals in a normal standing position and the results were used as baseline values. It was defined as the angle on the flexion side of the joint and corresponded to the physiological position of the elbow with the animal standing. The goniometer was placed over the lateral epicondyle of the humerus. The stationary proximal arm was aligned with the greater tubercle of the humerus (*tuberculum majus humeri*), while the movable arm of the goniometer moved with the styloid process of the ulna during movement of the elbow in the sagittal plane. For measurement of rotational movement, the elbow and metacarpal joint were flexed 90° and the degree of supination and pronation was determined (18).

The anatomical and biomechanical characteristics of the elbow joints obtained at post mortem from seven rabbits and seven cats were investigated and compared using computed tomography (CT) (Somatom AR Star, Somaris I4 VB41A, Siemens AG, Erlangen). The primary slices were taken in the sagittal plane relative to the longitudinal axis of the limb. Spiral CT was used to obtain 1-mm slices of the elbow, and the data sets were used to produce three-dimensional (3D) reconstructions of the joints for species comparison. The bone density of the elbow was also determined using CTOAM. The maximum bone density at a defined depth perpendicular to the joint surface was measured at various points using the 3D reconstructions. Maximum intensity projection (MIP) maps were superimposed on the surface of 3D virtual reconstructions where the values were displayed as false-colour maps. The limit of the false-colour maps was 500–2000 Hounsfield units (HU) (see colour bar patterns, ▶Figs. 5–8).

Finally, stabilization of elbow bone specimens was investigated using cerclage wire. In accordance with the course of the collateral ligaments, a hole was drilled at the proximal (normally located slightly eccentric and proximal to the rotational axis of the joint) and distal insertions of the humeroulnar collateral ligaments. A cerclage wire (▶Figs. 2 and 3) was passed through the holes and tightened with the elbow at an angle of approximately 118° (nor-

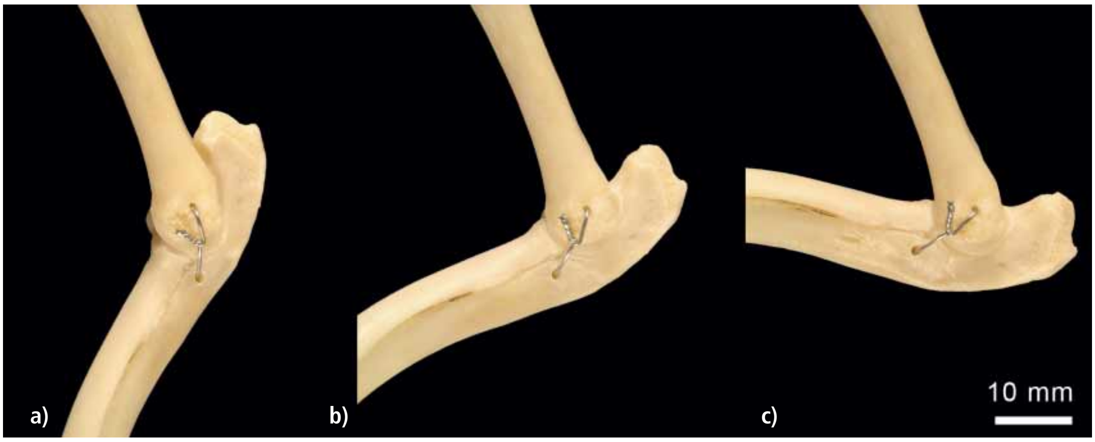

Fig. 3 Medial view of a rabbit elbow in an extended (a) and flexed (b, c) position after fixation of caudal luxation using wire.

mal angle of elbow in the standing animal). The degree of stabilization and wire tension through the drilled holes were assessed by flexing and extending the joint.

Results

A search of the medical records of the Department of Surgery, Veterinary Faculty of the Ludwig-Maximilians-University of Munich, from 1995 to 2005, revealed 30 joint luxations in rabbits; elbow luxation comprised 70% of cases and hip luxation 30%. In the same time period, there were 349 joint luxations in dogs and 321 in cats; only 17% and 19%, respectively, involved the elbow. Caudal luxation occurred in the majority of rabbits (9/15)[1], whereas lateral luxation predominated (73/74)[2] in dogs. In cats, the direction of elbow luxation was medial in (29/57)[3], lateral in (22/57)[3] and caudal in (6/57)[3].

Evaluation of the rabbit elbows revealed that this joint is a hinge joint as well as a "snap joint". The lateral and medial collateral ligaments originate from an eccentric position on the distal humerus, and the ulnar crus is much stronger than the radial crus, which consists of only a few fibres. The ulnar crus of the collateral ligament inserts at approximately the level of the head of the radius and its caudal attachment to the ulna (▶Fig. 4). Gross evaluation of the elbow musculature in rabbits showed that the *m. pronator teres* was easily identified, but the *m. supinator* was not visible. An aponeurosis originating from the *m. biceps brachii* extended to the *m. extensor carpi radialis* (▶Fig. 5 b,c) at the cranial aspect of the forearm in rabbits. This structure could not be identified in cats (▶Fig. 5a).

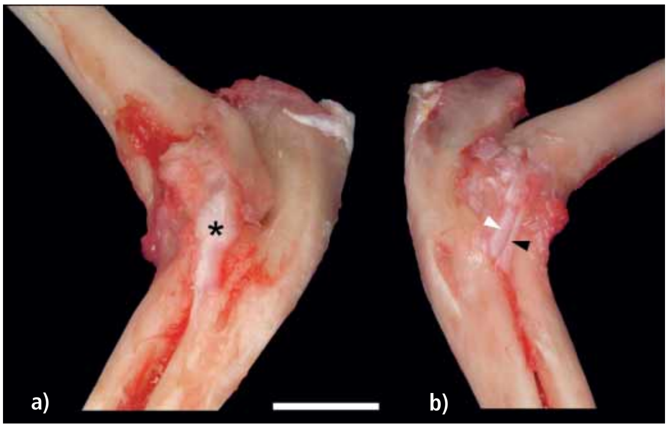

Fig. 4 Left elbow joint of a 2.7-kg rabbit: a) Lateral view, b) Medial view. The lateral collateral ligament (*) has only one crus; the medial collateral ligament has two crura, the radial (black arrowhead) and the ulnar (white arrowhead).

The range of flexion and extension in the 14 elbow joint specimens from rabbits ranged from 44° ± 5° (median = 45°) to a mean of 158° ± 10° (median = 160°). This corresponded to a sagittal range of motion of 114° (median = 115°). Passive outward rotation was a mean of 17° ± 6° (median = 15°), and pronation was a mean of 6° ± 3° (median = 5°), resulting in a mean range of rotation of 23° (median = 20°). In live rabbits, the angle of the elbow while standing was a mean of 118° ± 8° (median = 118°), maximum flexion was a mean of 44° ± 3° (median = 45°) and maximum extension was a mean of 158° ± 7° (median = 155°). The resulting range of motion was a mean of 110° (median = 114°) in the sagittal plane. In the normal standing position, the forearm was rotated outwards (supination) a mean of 11° ± 2° (median = 10°). Further passive supination was possible to a mean maximum of 16° ± 3° (median = 15°). Pronation was possible to a mean of 5° ± 1° (median = 5°). This resulted in a maximum mean range of rotation of 21° (median = 20°).

Comparison of rabbit and cat elbows using the computed tomographic 3D reconstructions showed that unlike cats, rabbits have a central sagittal ridge on the condyle of the humerus, which

1 The direction of luxation could not be determined on radiographs of 6 rabbits, which reduced the total number of rabbits from 21 to 15.
2 The direction of luxation using radiographs was determined using a larger number of patients, which increased from 59 to 74.
3 Luxation of the radius (e.g. Monteggia fracture; n = 3) was included in the absolute number of elbow luxations but not in determination of the direction of luxation.

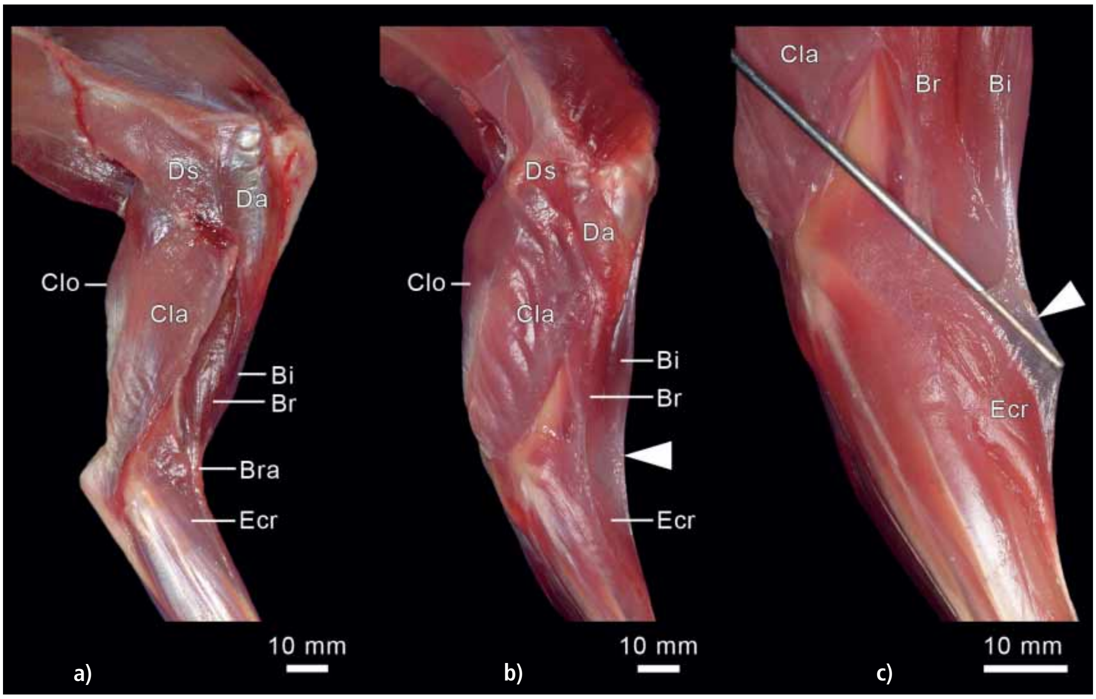

Fig. 5
Right forelimb of a cat (a) and rabbit (b, c) (these are the same animals shown in figures 1 and 4). The arrowhead in b and c indicates the connection consisting of fascial tissue between the m. biceps brachii and m. extensor carpi radialis. Such a strong connection is only seen in rabbits. Bi – m. biceps brachii; Br – m. brachialis; Bra – m. brachioradialis; Cla – lateral head of the m. triceps brachii; Clo – long head of the m. triceps brachii; Da – m. deltoideus, pars acromialis; Ds – m. deltoideus, pars scapularis; Ecr – m. extensor carpi radialis.

acts as a guiding surface (▶Fig. 6). As well, the olecranon of rabbits has a narrower and deeper trochlear groove (*incisura trochlearis*) and longer *tuber olecrani* than cats. In rabbits, the radius is situated slightly anterior to the ulna, whereas in cats, it sits laterally. The coronoid process of the medial ulna has a wide articulation with the radius in cats, whereas in rabbits it is flattened. Bone density was greatest in the caudal joint region of rabbits, particularly the trochlear groove of the ulna (*incisura trochlearis ulnae*). The ventral aspect of the humeral condyle was the densest area in the caudal region of the joint (▶Figs. 7, 8). In contrast, bone density of the feline elbow was distributed fairly evenly so that a reproducible main zone of loading could not be identified (▶Figs. 9, 10).

Passive flexion and extension of the elbows stabilized with wire revealed no loosening of the implant. The range of flexion and extension was normal, although with flexion greater than the normal angle of approximately 118° there was a small amount of resistance to overcome, consistent with the function of a „snap joint“.

Discussion

In agreement with other studies (6), our results showed that elbow luxation was the most common type of luxation in rabbits, whereas hip luxation occurred more often in cats and dogs (1, 20). This

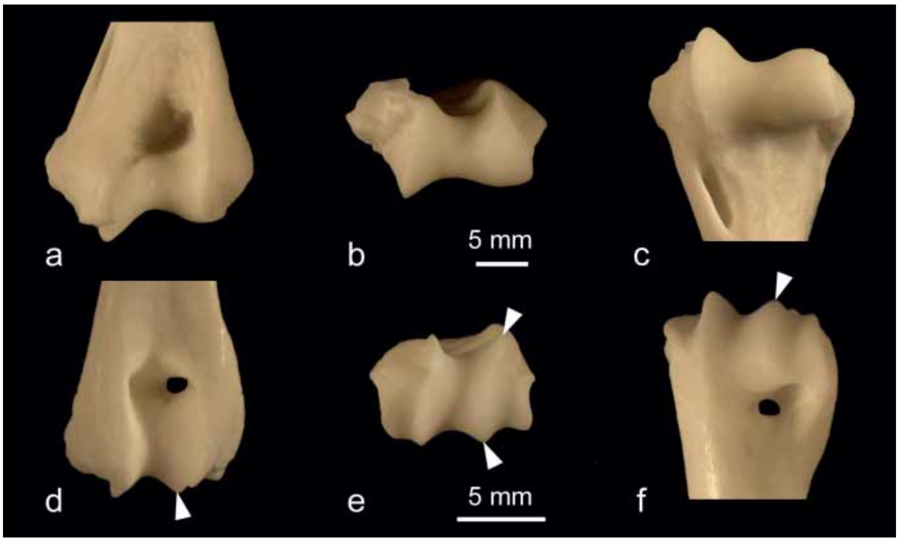

Fig. 6
Comparison of the distal humerus of a cat (a–c) and rabbit (d–e). In the rabbit, there is a central sagittal crest (white arrowhead) in the joint region, which acts as a guide to firmly anchor the proximal ulna in the sagittal plane.

difference has been attributed to the type of locomotion of rabbits, which differs from that of cats and dogs (6).

During sagittal movement of the elbow, the collateral ligaments are under maximum tension at the midway point and movement beyond this point results in the joint "snapping" into a flexed or extended position. Thus, a distinct resistance must be overcome when completely extending the elbow passively. This occurs because the origin of the collateral ligaments on the humerus is proximal (eccentric) to the joint axis. This anatomical peculiarity is also seen in horses and to a lesser extent dogs.

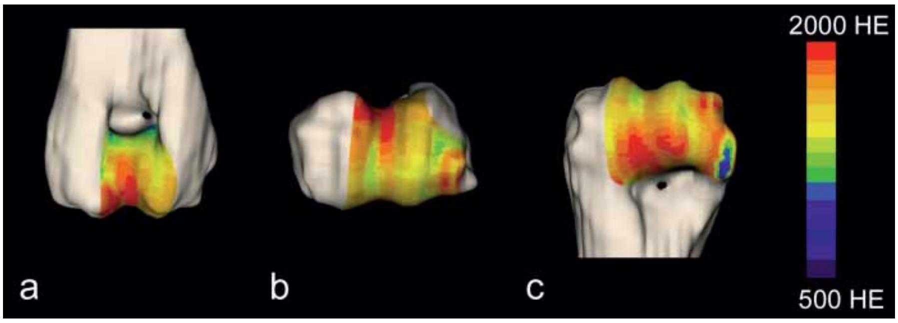

Fig. 7
Topographic representation of the bone density distribution of the right humeral condyle of an adult castrated male rabbit (1.34 kg); Caudal view (a), distal (b) and cranial (c). (3D-reconstruction from CT data)

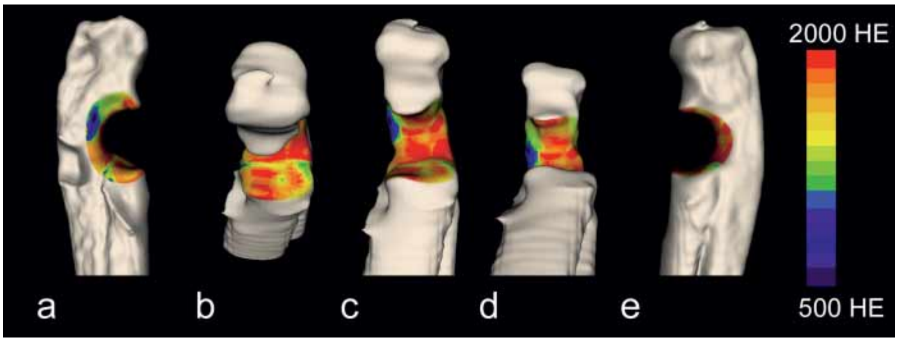

Fig. 8
Topographic representation of the bone density distribution of the trochlear notch of the right ulna and head of the right radius of an adult castrated male rabbit (1.34 kg); Lateral view (a), proximal (b), cranial (c), distal (d) and medial (e). (3D-reconstruction from CT data)

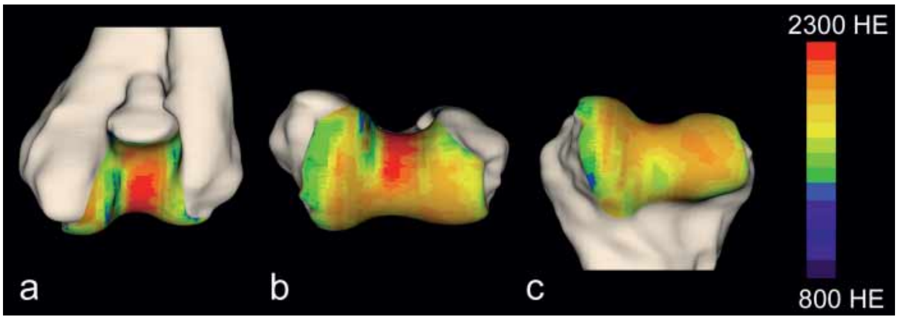

Fig. 9
Topographic representation of the bone density distribution of the right humeral condyle of an adult female short hair cat (2.22 kg); Caudal view (a), distal (b) and cranial (c). (3D-reconstruction from CT data)

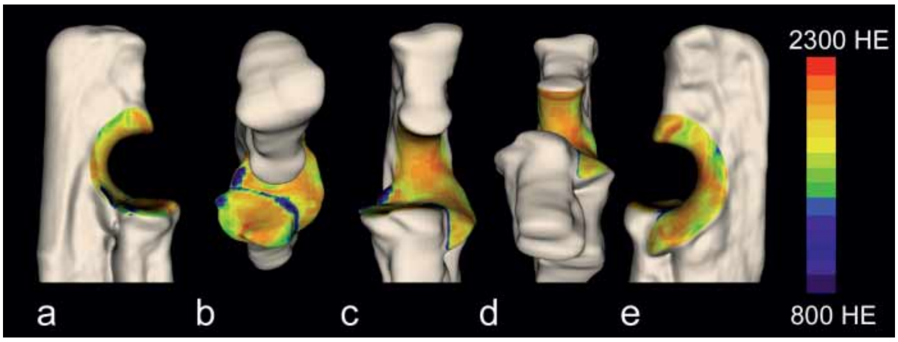

Fig. 10
Topographic representation of the bone density distribution of the trochlear notch of the right ulna and the head of the right radius in an adult female short hair cat (2.22 kg), Lateral view (a), proximal (b), cranial (c), distal (d) and medial (e). (3D-reconstruction from CD data)

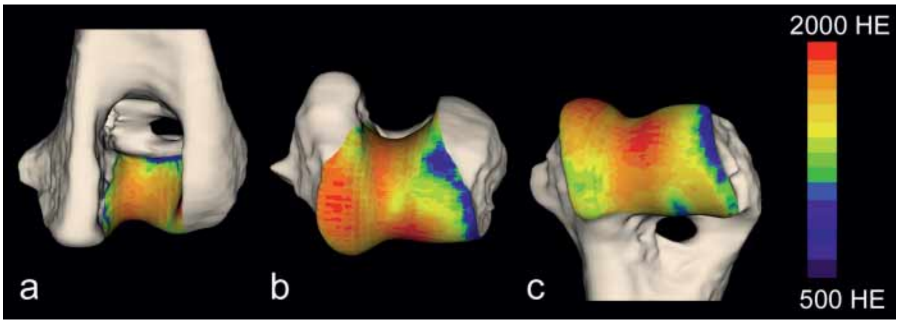

Fig. 11
Topographic representation of the bone density distribution of the right humeral condyle of a two-year-old, male, mixed breed dog (27.5 kg); caudal view (a), distal (b) and cranial (c). (3D-reconstruction from CT data)

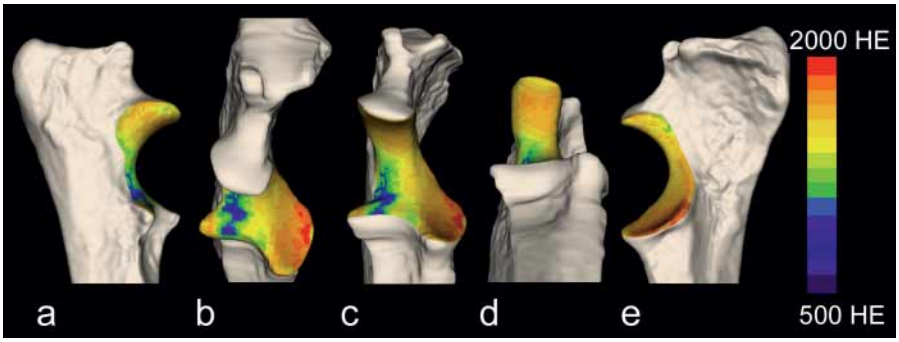

Fig. 12
Topographic representation of the bone density distribution of the trochlear notch of the right ulna of a two-year-old, male, mixed-breed dog (27.5 kg); Lateral view (a), proximal (b), cranial (c), distal (d) and medial (e). (3D-reconstruction from CT data)

The elbow of carnivores functions strictly as a hinge joint, in which the movement is perpendicular to the rotational axis of the joint. In contrast to rabbits, there is no resistance when the elbow is passively flexed and extended. An aponeurosis fanning out from the tendon of the *m. biceps brachii* and extending to the *m. extensor carpi radialis* was seen in rabbits (▶Fig. 5), and was reminiscent of the *lacertus fibrosus* in horses. This structure serves to flex the elbow during simultaneous flexion of the shoulder joint. It appears logical to speculate that this aponeurosis provides mechanical support to the elbow, which in the rabbit is loaded mainly in a flexed position. In contrast to cats, the well-developed central sagittal ridge of the humeral condyle in rabbits protects the joint from lateral and medial dislocation, but limits outward and inward rotation of the forearm. In the sagittal plane, the range of motion between maximum flexion and extension in rabbits is similar to that in cats (19) and dogs (1, 17).

Vollmerhaus et al. (19) reported that the angle of the elbow in standing cats was 110° and the range of motion from maximum flexion to maximum extension 120–135°. In dogs, the range of motion of the elbow was breed-dependent and varied from 100° in dachshunds to 140° in poodles (17). Our study found that the range of sagittal motion in the rabbit elbow was 114°. With regard to the motion of the proximal radioulnar joint, maximum pronation of the forearm in cats was achieved with the elbow flexed and at a right angle. A maximum of 90–105° of supination was possible. The feline elbow was most stable when the joint was at a standing angle and pronated (19). The range of rotational motion of the canine elbow joint is markedly smaller than that of cats (15). It is breed-dependent and varies from 68° (German shepherd dog) to 76° (dachshund) (1, 17), whereas in rabbits it is only 21°.

Locomotion varies among species, and the biomechanical function of the elbow is specially suited for each. Roos et al. (15) reported that in cats, supination of the forearm was active, whereas this movement of the proximal radioulnar joint only occurred passively in dogs. Supination of the forearm in cats is used mainly for catching prey but also for fighting and raising offspring. The extensive range of motion of the feline forearm is evident during grooming when the cat uses its forepaw to reach otherwise inaccessible areas. Dogs, however, use the stability of the proximal radioulnar joint for running after prey and high-speed movement. The ability of dogs to stop abruptly and negotiate tight curves is afforded by the support of the fixed forelimb. In rabbits, the hind limbs propel the body forward while the forelimbs support the body weight and the elbows provide mediolateral stability. Rabbits also use their forepaws for grooming, especially the head and ears, but the range of forepaw motion is much more limited than in cats. Rabbit behaviour does not require extensive outward movement of the forepaw, which explains why rabbits do not have a supinator muscle, which is short and strong in cats.

Because of good lateral stability and limited rotational movement of the elbow, luxation is usually in a caudal direction in rabbits. In dogs, the elbow usually luxates laterally, and no one direction predominates in cats. Traffic accidents in which the body of the animal pivots around the flexed elbow are the most common cause of elbow luxation in dogs. There is limited lateral joint stability in the flexed position because the anconeal process is not anchored in the *fossa olecrani*, which allows the humeral condyle to slide craniomedially over the head of the radius. Elbow luxation in cats and rabbits is usually the result of a jump or fall from a height. The manner in which the cat lands on its paws after a fall determines the direction of luxation (17), whereas in rabbits, the more stringent condylar structure of the humerus predisposes to caudal luxation. However, it is not clear whether dislocation occurs with the elbow flexed (6) or when it is over-extended during impact. Under normal conditions, the eccentric origin of the collateral ligaments and resultant „snap" function as well as the aponeurosis on the cranial aspect of the joint hamper over-extension. Measurement of subchondral bone density via CTOAM, which showed increased values in the caudal region of the rabbit elbow, indicated that there was habitual compressive loading in the half-flexed position. Maierl (8; ▶Figs. 11, 12) reported that the bone density in dogs was also greatest in this region, particularly caudal to the *trochlea humeri* and medial coronoid process of the ulna. This region of the joint is often involved in elbow dysplasia in dogs. In contrast, subchondral bone density had a diffuse distribution with no distinct area of habitual loading in cats.

With regard to treatment of caudal elbow luxation in rabbits, it is advantageous to apply a Velpeau sling after reduction to allow the soft tissues to heal. The flexed forearm maintains the humerus in a reduced position and relieves tension on the cranial soft tissues. This measure is often curative in rabbits and in cats sometimes as well. In dogs, however, the elbow must be immobilized in an extended position for several days after closed reduction to stabilize the anconeal process in the olecranon fossa. Conservative treatment of elbow luxation usually has a good prognosis when carried out early on (1, 20). Campbell (2) described a method to evaluate the efficacy of closed reduction in dogs, in which the stability of the collateral ligaments is assessed by flexing the elbow and carpus by 90° and rotating the forearm inwards and outwards. When elbow instability occurs after closed reduction, the authors recommend surgical stabilization to prevent impaired joint motion and cubital arthrosis (2, 16). Whether this method of assessing elbow stability is effective in rabbits and cats requires further study. Testing on rabbit cadaver specimens showed that compared with cats and dogs, the rabbit elbow has better lateromedial stability because of the central sagittal ridge on the humeral condyle. Rabbits suffering from medial or lateral elbow luxation despite this anatomical feature likely have damage to the collateral ligaments, which requires surgical treatment.

Of the four rabbits that incurred reluxation of the elbow (n = 21), three had medial or lateral luxation. In those cases, a Velpeau sling alone provides inadequate stability, and a stabilization technique that mimics the function of the collateral ligaments would be indicated. Numerous surgical techniques have been described for cats and dogs (1, 3, 5, 20); however, it is questionable whether they can be applied to rabbits. Thus, the only published treatment recommendations for rabbits relate to transarticular wire fixation, lateral/medial application of single U sutures, or „isometric" sutures (4, 7, 13). The latter method was employed in three rabbits, and suture material with a long absorption time provided sufficient stabilization and allowed satisfactory mobility. The suture material ran from the distal humerus to the proximal ulna over the centre of the humeral trochlea and was tied laterally. Our goal was to provide stabilization that restored the normal anatomy as closely as possible. Because soft tissue damage on the lateral and medial aspects of the elbow increases the risk of recurring luxation, (the sagittal component of the luxation can usually be managed using a Velpeau sling), it seems prudent to replace the humeroulnar collateral ligament as accurately as possible rather than using the method of Lorinson and Grösslinger (7). The suture material or wire can be easily anchored through the drill holes and no additional implant material is required to maintain the reduction. The technique used in the present paper on elbow specimens provided good stability without compromising the range of joint motion. However clinical trials are necessary to investigate the in-vivo efficacy of this method. Furthermore, it is not clear whether secondary post-traumatic arthrosis, which we have identified as a risk after open reduction of elbow luxation in rabbits, can be minimized using this technique.

Clinical relevance

Rabbits require little rotational movement of the elbow joint for locomotion, browsing for food and grooming. Instead, rabbits require lateromedial stability, which is afforded by the central sagittal ridge of the humerus. Rabbits that fall from a height are predisposed to caudal dislocation of the antebrachial bones. This type of luxation can usually be treated with closed reduction and relief of the traumatised cranial joint capsule region with application of a Velpeau sling. Lateral elbow luxation is uncommon but more prone to recurrence. In such cases, replacement of the humeroulnar ligaments may be helpful. The transosseous technique that we used on the cadaver specimens provided good stabilisation with normal joint motion. However, clinical studies are needed to determine its efficacy.

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