The role of the oblique ligament in the mechanical behavior of the medial collateral ligament of the mongrel dog elbow joint – some biomechanical aspects

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ABSTRACT. This study investigated the oblique ligament mechanical contribution to the medial collateral ligament of the canine elbow joint. Fifteen dogs were used for the study of the failure load, displacement, and energy absorption of the medial collateral and oblique ligaments of the canine elbow joint, associate and separately in the joint. Medial collateral ligament failure load and energy absorption were significantly higher in relation to the isolated oblique ligament. When the ligaments were associated in the joint, they presented an increment in failure load, displacement and energy absorption in relation to the ligaments analyzed separately. It was concluded, therefore, that the oblique ligament could have an important paper in the stability of the canine elbow joint, as it favors the medial collateral ligament resistance to the tensile load, one of the main stabilizer of the elbow joint.

Key words: biomechanics, oblique ligament, medial collateral ligament, elbow, dog.

RESUMO. O papel do ligamento oblíquo no comportamento mecânico do ligamento colateral medial da articulação do cotovelo de cães SRD – alguns aspectos biomecânicos. O propósito deste trabalho foi analisar a contribuição mecânica do ligamento oblíquo frente ao ligamento colateral medial na articulação do cotovelo do cão. Quinze cães foram utilizados para a realização de ensaio de tração para a análise da carga, alongamento e tenacidade dos ligamentos colateral medial e oblíquo, isolados ou associados. A carga máxima e o valor da tenacidade suportada pelo ligamento colateral medial isolado foram significativamente maiores em relação ao ligamento oblíquo isolado. Quando associados, apresentaram um incremento na carga máxima, no alongamento e na tenacidade em relação aos ligamentos analisados isoladamente. Concluiu-se, portanto, que o ligamento oblíquo tem um importante papel na estabilidade da articulação do cotovelo do cão, já que aumenta a resistência à tração do ligamento colateral medial, um dos principais estabilizadores da referida articulação.

Palavras-chave: ensaio mecânico, ligamento oblíquo, ligamento colateral medial, cotovelo, cão.

Introduction

Ligaments are short bands of tough but flexible fibrous connective tissue that bind bones together and work stabilizing the joints, while they allow normal movements (Payne and Tomlinson, 1996). Frank *et al.* (1985) observed that ligaments, despite their simple appearances and relative scientific obscurity, are highly sophisticated structures with equally sophisticated functions.

The elbow is a composite joint classified as a hinge type joint. It is composed of five ligaments, the lateral and medial collateral ligaments, the oblique ligament, the annular ligament and the olecranon ligament (Campbell, 1969; Denny, 1993; Evans, 1993). According to Denny (1987), strong collateral ligaments and the anconeal process, which fits deep into the olecranon fossa of the humerus, prevent lateral movement of the elbow. The medial and lateral collateral ligaments connect the three bones of the cubital joint. In addition, the oblique ligament, the olecranon ligament and the annular ligament further potentiate the stability of the elbow (Taylor, 1996).

Oliveira *et al.* (2003) described the medial collateral ligament of the canine elbow joint as divided in cranial and caudal portions. The caudal portion is longer and narrower (with mean length values of 3,30 ± 0,36 cm and width of 0,26 ± 0,06 cm for medium-sized dogs) and penetrates the interosseous space, attaching to the proximal caudolateral surface of the radius caudally to the insertion of the cranial portion of the lateral collateral ligament.

Oblique ligament is capsular and also becomes separated in cranial and caudal portions. The cranial portion (with mean length values of 2.94 ± 0.30 cm and width of 0.28 ± 0.08 cm for medium-sized dogs) attaches to the proximal medial border of the radius, bypassing the tendons of insertion of the brachial muscle and biceps brachii muscle. The cranial portion of the medial collateral ligament fuses with the caudal portion of the oblique ligament (Oliveira *et al.*, 2003). In this transition area between the two ligaments, the collagen fibers form a right angle, suggesting the relationship between the medial collateral ligament and the oblique ligament and reinforcing the biomechanics of these ligaments (Oliveira, 2002).

The ligaments and tendons are characterized, according to Benjamin and Ralphs (1998), for the great strain they support and they are formed predominantly by collagen fibers.

Benjamin and Ralphs (1997) reported that 70% to 80% of the dry weight of tendons is composed by collagen, and most of this (90%, according to Frank *et al.*, 1985) is type I collagen with smaller amounts of type III, V and VI collagen.

Bargmann (1968) and Lapiere *et al.* (1977) stated that the association of collagen fibers in networks determines the architectural organization of the connective tissue and conditions their mechanical properties, i.e., if the mesh angles are wide, the mobility and the displacement capacity of the tissue are also elevated. The molecular structure of the collagen fibrils determines the physical structure of the networks, with type I collagen forming thick fibers networks, type III forming isolated fine fibers, and mixtures of types I and III forming networks whose thickness varies with the respective concentrations of the two types of molecules (Lapiere *et al.*, 1977). The reticular fibers are formed by type III collagen (Junqueira and Carneiro, 1999).

Frank *et al.* (1985) reported that ligaments are anisotropic, being oriented to resist tension along their long axes, and possess time- and history-dependent viscoelastic properties.

Liao and Belkoff (1999) using the knee medial collateral ligament of rabbits, created a failure model for ligaments which assumes that sequential uncrimping and stretching of collagen fibers is responsible for the mechanical response of ligament. Vogelsang *et al.* (1997) related that the medial collateral ligament is less strong and less stiff than the lateral collateral ligament; however, their material properties are similar.

Shimano and Shimano (2000) reported that every object submitted to external strains tends to be deformed, presenting an internal resistance against that deformation. The authors also discuss some theoretical aspects of the mechanical stimulation: as the forces act in the longitudinal axis tending to elongate the object or to break it, it is called tensile load. Energy absorption is one of the main material mechanical properties, defined as the energy absorbed by the material until the moment previous to the rupture, i. e., the material capacity to resist to high loads with large deformation without failure.

The contribution of the ligaments to the elbow stability is a product of the knowledge of the morphology and the biomechanical parameters which is fundamental for the maintenance of the integrity of the soft tissues that compose the elbow (Regan *et al.*, 1991; Vogelsang *et al.*, 1997). As the artroplasty is also developed for the use in dogs, it is necessary to know the anatomical characteristics and the functional properties of the ligaments of this species in full detail for the correct intervention (Vogelsang *et al.*, 1997).

Considering the contiguity of the caudal portion of the oblique ligament and the cranial portion of the medial collateral ligament, the purpose of this work was to analyze the mechanical contribution of the oblique ligament to the medial collateral ligament of the canine elbow joint.

Material and methods

Fifteen medium-sized adult mongrel dogs (08 males and 07 females) were studied for the medial collateral and oblique ligaments analysis of failure load, displacement and energy absorption. The animals were donated by the Parasitological Research Center (CPPar) of Unesp, Jaboticabal, São Paulo State, Brazil. The weight and length from the nuchal crest to the joint between the first and second coccygeal vertebra were recorded. After euthanasia (processed with anesthetic overdose associated with endovenous administration of potassium chloride), fresh right and left thoracic limbs were dissecated, and the joints constituted by the humerus, radius, ulna with one or both mentioned ligaments were collected (Figure 1A and 1B). The others ligaments were severed previously.

As Woo *et al.* (1986a) proposed, due to the limited length of the ligaments, it was not possible to examine ligament properties accurately in their isolated state. Testing a short ligament substance would introduce errors when evaluating the mechanical properties of the tissue due to non uniform tensile stress distribution and stress concentration at the edges of the clamps, as well as slippage of the specimen within the clamps, leading to submaximal ultimate mechanical properties. Thus, the humerus-ligament(s)-radius/ulna complex remained as the only viable choice for successful tensile testing (Figure 1C). The proximal portion of the ulna was removed by making a transverse osteotomy through the bone at the level of mid-trochlear notch (Figure 1D).

The joints submitted to the tensile strain were placed in a testing apparatus (EMIC®) of the Laboratory of Bioengineering of the University of Medicine from Ribeirão Preto/USP, Brazil, until 24 hours after the death of the animals. The bones were rigidly fixed, using clamps. Bone-ligament-bone preparations was put in the testing apparatus (Figure 1C) and tractioned in a rate of 10 mm/minute, with tension from 0.5 kgf to 80 kgf.

Joints were divided in three groups, in one group the medial collateral ligament were tested separately in the joint (total joints = 9); in another group the isolated oblique ligament were loaded in the joint (total joints = 11) and the last group had both ligaments tested together (total joints = 10).

Computer-generated load-displacement curves were used to determine values for failure load and displacement at failure load. Load-displacement curves were generated from these data and allowed calculation of the energy absorption to failure by the software Origin 6.0®.

The numerical data obtained were analyzed statistically using variance analysis and Tukey's test by the software Statistic Analysis System (SAS, 1985). Summary results are presented as mean ± Standard Deviation (SD).

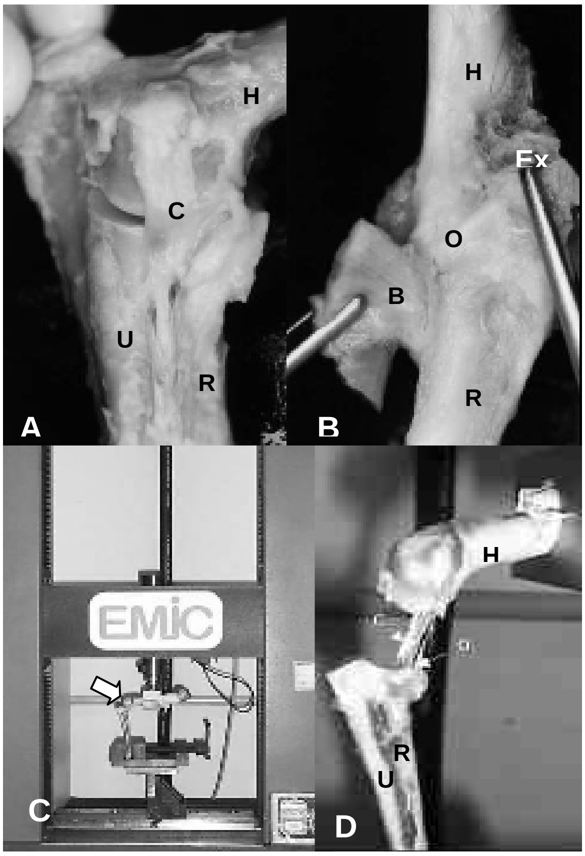

Figure 1. A. Canine elbow joint medial view, showing the medial collateral ligament (C), humerus (H), radius (R) and ulna (U) before olecranon osteotomy. **B**. Canine elbow joint cranial view with oblique ligament (O) and the muscles around it (*m. extensor carpi radialis* and *m. extensor digitorum comunis* – ExM; *m. biceps brachii* and *m. brachialis* – BM). **C**. Canine elbow joint (white arrow) in the testing apparatus (EMIC®) in tensile loading. **D**. Detail of the canine elbow joint during the tensile test, showing the ligament rupture. Note the olecranon osteotomy (C – medial collateral ligament; O – oblique ligament; H – humerus; R – radius; U – ulna)

Results and discussion

The dogs presented a mean weight ± SD of 10.6 ± 2.8 Kg and mean length ± SD of 60.1 ± 2.5 cm.

It was decided to use fresh joints or frozen until 24hs. Studies of the effects of postmortem storage by freezing on ligament tensile behavior demonstrated that a proper and careful storage by freezing for up to 3 months to -20°C would have little or no effect on the biomechanical properties of the ligaments, according to Woo *et al.* (1986b).

In all the tests the ligaments failed in the mid-substance. Woo *et al.* (1986a) made mechanical stimulation in medial collateral ligament of the rabbit knee of various ages and stated that the junctions for the younger animals are consistently weaker than those for the ligament, whereas older animals have the attachment area stronger.

Failure load and the value of the energy absorption supported by the medial collateral ligament (298.45 ± 71.55 N and 1.55 ± 0.50 J, respectively) were significantly higher in relation to the oblique ligament (182.87 ± 45.84 N and 0.94 ± 0.32 J). When the ligaments were associated in the joint, they presented higher failure load (361.21 ± 89.77 N), however not differing statistically of the isolated medial collateral ligament failure load ($p>0.01$). Displacement (0.021 ± 0.004 m) and the energy absorption (2.66 ± 0.74 J) of the joints with both ligaments presented greater values ($p<0.01$) in relation to the ligaments analyzed separately (Table 1 and Figure 2 to 4).

Table 1. Mean (± SD) failure load (in Newtons, "N"), displacement (in meters, "m") and energy absorption (in Joules, "J") of the canine elbow medial collateral and oblique ligaments during biomechanical testing. Total joints = 30.

Groups	Failure load (N)	Displacement (m)	Energy absorption (J)
Medial Collateral Ligament	298.45 ± 71.55^a	0.015 ± 0.003^b	1.55 ± 0.50^b
Oblique Ligament	182.87 ± 45.84^b	0.013 ± 0.002^b	0.94 ± 0.32^c
Medial Collateral + Oblique Ligament	361.21 ± 89.77^a	0.021 ± 0.004^a	2.66 ± 0.74^a
Coefficient of variation	25.48	19.44	31.90
F value	17.32★	13.57★	26.98★

★ = significant to 1%. ^{a,b,c} = different letters means statistical differences between the groups

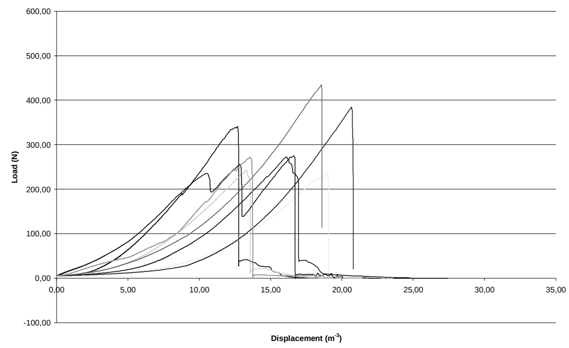

Figure 2. Load-displacement curves of isolated medial collateral ligaments. Total joints = 9.

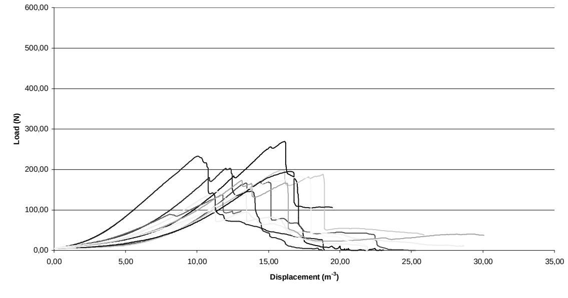

Figure 3. Load-displacement curves of isolated oblique ligaments. Total joints = 11.

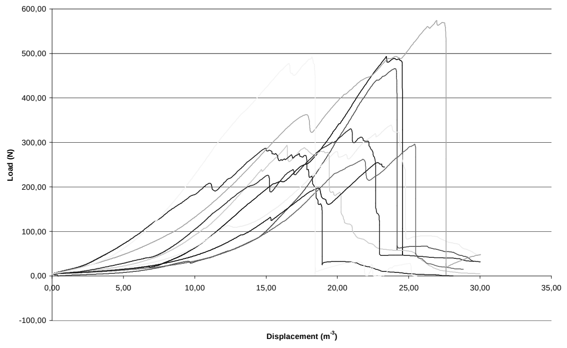

Figure 4. Load-displacement curves of medial collateral ligament associate to the oblique ligament. Total joints = 10.

Canine medial collateral ligament and oblique ligament, during the tensile tests demonstrated elastic properties. Vogelsang *et al.* (1997) described that the medial collateral ligament does not present detectable elastin. Collagen in crimp pattern has an elongating property even without the aid of elastic fibers, due to its high elasticity module (Bargmann, 1968; Viidik and Ekholm, 1968; Amiel *et al.*, 1984; Frank *et al.*, 1985; Yahia *et al.*, 1990; Strocchi *et al.*, 1992). Microscopically, the medial collateral ligament presented similar morphological pattern when it was not submitted to tension. Displacement observed when each ligament was tested separately in the joint was significantly smaller than both ligaments associated, demonstrating that elastic property can be increased according to the properties of the adjacent tissues. These notes about the displacement also correspond to the failure load supported by the isolated and associated ligaments in the joint.

The pattern of the graphs of the failure load and displacement observed in canine (Figures 2 to 4) are in agreement with the results obtained by Viidik (1972) and Woo *et al.* (1983) in tendon and in knee medial collateral ligament of rabbits, respectively.

Conclusion

Medial collateral ligament has higher failure load, displacement, and energy absorption than the oblique ligament. The association of both ligaments makes an increase of these values, concluding that oblique ligament could have an important role in the stability of the canine elbow joint, as it favors the integrity and it increases the medial collateral ligament resistance to the tensile load.

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