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## RESEARCH ARTICLE



# Biomechanical testing of canine tibiae: Changes resulting from different tibial tuberosity advancement techniques – Pilot study

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## ABSTRACT

The objective of the present pilot study was to determine the force required to break (a) intact canine tibiae, (b) tibiae following the osteotomy of the tibial tuberosity and (c) tibiae following Tibial Tuberosity Advancement- (TTA-) rapid surgery. Six pairs of tibiae of dogs between 15 and 35 kg body weight were used in a cadaver study. Three groups were created with four tibiae in each group; intact (Group 1), osteotomy of the tibial tuberosity and tibial crest (Group 2) and TTA-rapid (Group 3). The tibiae were put under static axial compressive load, applied until failure. The force required to break the tibiae was termed maximal force ( $F_{\max}$ ). The mean of  $F_{\max}$  was  $8193.25 \pm 2082.84$  N in Group 1,  $6868.58 \pm 1950.44$  N in Group 2 and  $7169.71 \pm 4450.39$  N in Group 3. The sample size was small for a statistical analysis but as a preliminary result, we have determined the force ( $F_{\max}$ ) required to break canine tibiae. Furthermore, we hypothesise that osteotomies result in weakening of the tibial structure.

## KEYWORDS

CTTA, TTA, cranial cruciate ligament rupture, biomechanical study, cadaver study, ex-vivo study

## INTRODUCTION

The rupture of the cranial cruciate ligament (CCL) of the stifle joint is a common cause of hind limb lameness and secondary osteoarthritis in dogs (Krotscheck et al., 2016). According to a study conducted in the US, the three most frequently performed surgical techniques are Extracapsular Ligament Repair (ECR) in small breed dogs (<9.1 kg), and Tibial Plateau Leveling Osteotomy (TPLO) or Tibial Tuberosity Advancement (TTA) in larger breeds (>9.1 kg) (Duerr et al., 2014).

One of today's paramount questions in small animal orthopaedics is the choice of surgical technique for CCL repair. Several studies assessing short- and long-term outcomes of different surgical techniques are available. A functional prospective study by Krotscheck et al. (2016) compared TTA, TPLO and ECR using force plate gait analysis. It concluded that limb function returned to normal with all three techniques in the walk, but in a trot, limb function matched that of the control group only after TPLO and not after TTA and ECR. A previous study by the authors concluded that patients of the TPLO group achieved similar limb function as the control group six months post-surgery, while the ECR group failed to return to normal (Nelson et al., 2013).

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Owner questionnaires and physical examination have also been used for long-term follow-up of limb function in various studies. One compared TPLO, TTA and Tight Rope (TR) techniques, finding TPLO and TR being superior to TTA in terms of overall limb usage. However, all three techniques generally resulted in satisfactory long-term outcomes (Christopher et al., 2013).

At the University of Veterinary Medicine, Budapest, TPLO and TTA-rapid have been the techniques of choice for CCL repair in dogs over 15 kg body weight. TTA-rapid, a modified version of the original TTA technique was described by Samoy et al., in 2014. Other forms of modified TTA procedures have also been described including TTA-CF (Tibial Tuberosity Advancement with Cranial Fixation) (Zhalniarovich et al., 2018), CTTA (Circular Tibial Tuberosity Advancement) and MMP (Modified Maquet Procedure) (Maquet, 1976). To our knowledge, CTTA has only been described in four studies, two of which constitutes our own work (Petazzonni, 2010; Rovesti et al., 2013; Zólyomi et al., 2015; Ipolyi et al., 2015).

In our experience, the transverse fracture of the tibia as a postoperative complication is more common with the TTA-rapid technique than with TPLO. Following the first one hundred TTA-rapid surgeries performed by our team, a total of three (3%) transverse tibial fractures occurred. In turn, the most recent one hundred TPLO procedures resulted in none (0%). A total of 66 CTTA procedures resulted in a single case of postoperative transverse tibial fracture (1.5%). According to the literature the complication rates for transverse tibial fracture with TPLO are 0.015–0.07% (Pacchiana et al., 2003; Stauffer et al., 2006; Gatineau et al., 2011), whereas with TTA and TTA-rapid this is in the range of 0.01–4.2% (Butterworth and Kydd, 2016; Costa et al., 2017; Dyll and Schmökel, 2017).

Biomechanical studies on canine bones so far mainly focused on bone healing or implant testing. A study published in 2014 compared five different implants available for the MMP technique, subjecting models to static compressive and cyclic loading (Etchepareborde et al., 2014). The same authors examined the resistance of the distal cortical hinge in case of varying degrees of advancement in MMP (Brunel et al., 2013). To the knowledge of the authors, no baseline biomechanical study of this sort on canine tibiae has been published to date.

This communication is a presentation of the results of a pilot study. *Ex-vivo* fracture tests of intact tibiae, tibiae that underwent osteotomy of the tibial crest and tuberosity (as performed in the original TTA technique) (Fig. 1) and tibiae that underwent TTA-rapid (Fig. 2) were performed.

Based on our own data and the relevant literature, in our main study we postulated that CTTA weakens the tibial bone structure to a lesser degree than does TTA-rapid. Another working hypothesis was that TPLO results in only a moderate weakening of the tibial bone construct as compared with TTA or CTTA.

## MATERIALS AND METHODS

### Experimental design

Six right and six left tibiae ( $n = 12$ ) of six dogs between 15 and 35 kg body weight euthanised for causes unrelated to the experiment were used in the study. All soft tissue envelope was removed from the bones. Mediolateral and craniocaudal radiographs of each tibia were taken to rule out any abnormality of the bone structure. The tibiae were then immersed in a 70% w/v ethanol solution. Three groups were created. Group 1 with intact tibiae ( $n = 4$ ), Group 2 with tibiae that were to undergo osteotomy of the tibial crest and tuberosity ( $n = 4$ ) (Fig. 1), and Group 3 with tibiae that were to undergo TTA-rapid ( $n = 4$ ) (Fig. 2). Care was taken not to include both the right and left tibiae of the same animal in the same group to help standardise the experiment.

### Processing of the bones

Before the procedures, tibiae were removed from the ethanol and were allowed to dry overnight at room temperature. On Group 1 tibiae no procedure was performed. On Group 2 tibiae, osteotomy of the tibial crest and tuberosity, while on Group 3 tibiae TTA-rapid was performed the following day using 9 mm TTA cages (Scinova). TTA cages were fixed in place using 2.0 mm drill bits and cortical screws 2.7 mm in diameter. After the procedures, the distal third of each tibia was cemented into a steel cylinder using polymethyl methacrylate (PMMA; Demotec, Demotec 90). The proximal third of each tibia was fixed into an aluminium bowl using epoxy resin (Novia, WWA + WWBHT) involving only the tibial plateau and tibial condyles (Fig. 3).



Fig. 1. Canine tibia after tibial crest and tuberosity osteotomy



Fig. 2. Canine tibia after Tibial Tuberosity Advancement- (TTA-) rapid surgery

### Mechanical testing

The tibiae were subjected to static axial compression. Fracture tests were carried out at the Materials Testing

Laboratory, Department of Polymer Engineering, Budapest University of Technology and Economics, using a calibrated ZWICK Z2020 tensile tester. Axial compression was sustained until failure and registered on a force-displacement curve. Failure (i.e. fracture) was defined as the first sharp drop of the force-displacement curve. The magnitude of the force at failure was defined as maximal force ( $F_{\max}$ ). Pre-loading force was 1 N, and a pre-loading velocity of  $100 \text{ mm min}^{-1}$  followed by a testing velocity of  $50 \text{ mm min}^{-1}$  was applied.

### RESULTS

In Group 1, four tibiae were used ( $n = 4$ ). However, in case of two samples ( $n = 2$ ) the tests had to be repeated due to an error in the clamping mechanism. In these two failed cases the top and the bottom end of the tibiae were not aligned parallelly, causing the bones to slip out of the frame sideways before fracture. The mean  $F_{\max}$  and standard deviation was  $8193.25 \pm 2082.84 \text{ N}$  for Group 1 and the median was 8444.56 N.

In Group 2, all four tests were successful at first attempt. The mean  $F_{\max}$  was  $6868.58 \pm 1950.44 \text{ N}$  and the median was 7153.51 N.

In Group 3, due to the same technical error as in Group 1, two tests had to be repeated. The mean  $F_{\max}$  and standard deviation was  $7169.51 \text{ N} \pm 4450.39$  and the median was 5593.78 N.

A summary of the results is shown in Table 1. Repeated test results are marked with an asterisk (\*). Figures 4, 5 and 6 demonstrate the force-displacement curve of each group.



Fig. 3. Canine tibia fixed with polymethyl methacrylate (PMMA) distally and epoxy resin proximally



Table 1. Results of a static axial compression test on canine tibia samples

	Group 1	Group 2	Group 3
Sample 1	8470.32 N	4342.43 N	4038.92 N*
Sample 2	8418.79 N	7875.20 N	4020.78 N
Sample 3	10467.87 N*	6431.81 N	7148.64 N
Sample 4	5416.00 N*	8824.88 N	13470.49 N*
Mean $\pm$ standard deviation	8193.25 $\pm$ 2082.84 N	6868.58 $\pm$ 1950.44 N	7169.71 $\pm$ 4450.39 N
Median	8444.56 N	7153.51 N	5593.78 N

Group 1 contains four ( $n = 4$ ) intact canine tibiae, Group 2 contains four ( $n = 4$ ) canine tibiae after tibial crest and tuberosity osteotomy and Group 3 contains four ( $n = 4$ ) canine tibiae after TTA-rapid surgery. The table summarises  $F_{\max}$  values, mean and standard deviation and median.  $F_{\max}$  was defined as the first sharp drop of the force-displacement curve. Results of repeated tests are marked with \*.

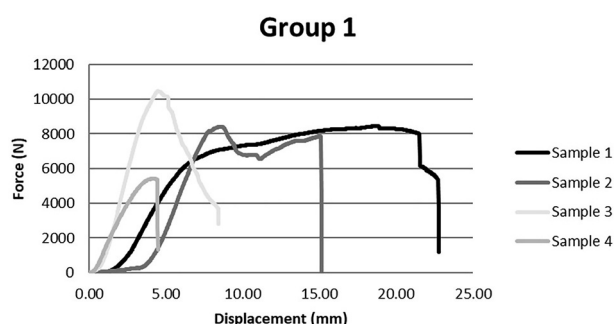


Fig. 4. Force-displacement curves of Group 1 (intact canine tibiae) samples after static axial compression test

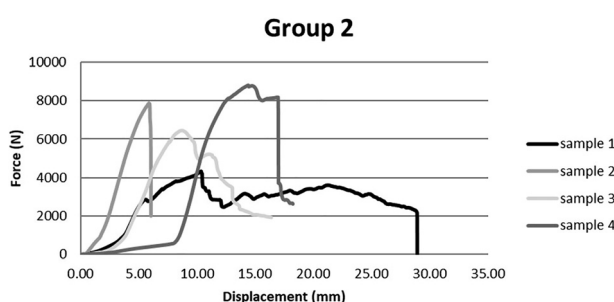


Fig. 5. Force-displacement curves of Group 2 (canine tibiae after tibial crest and tuberosity osteotomy) samples after static axial compression test

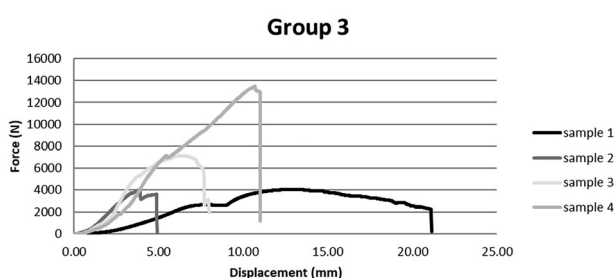


Fig. 6. Force-displacement curves of Group 3 (canine tibiae after TTA-rapid surgery) samples after static axial compression test

## DISCUSSION

The aim of this pilot study was to gain experience with the ZWICK Z020 tensile tester and the clamping mechanism as

well as to determine the force ( $F_{\max}$ ) required to break tibiae of dogs between 15 and 35 kg of body weight.

Based on the literature, two storage methods are available that do not affect the biomechanical properties of the bones. One of them is freezing, the other is alcohol immersion. According to a study that was published in 2006, there was no significant difference in the biomechanical properties of freshly prepared rat femur as compared with those frozen or stored in alcohol. Storage times over a month with any method studied could have an effect on the biomechanical properties of the bones and, thus, on the scientific results (Beaupied et al., 2006). In our study, the samples were stored for less than a month before the experiment. In the few biomechanical studies that were published in the veterinary scientific literature where canine bones were tested, freeze storage was preferred (Leitner et al., 2008; Filipowicz et al., 2009; Hoffmann et al., 2011). However, at the Materials Testing Laboratory, Department of Polymer Engineering, Budapest University of Technology and Economics alcohol storage was preferred, therefore this method was selected. In a previous study that examined the biomechanical properties of the metacarpal bones of horses, the same alcohol storage method was used (Tóth et al., 2014).

Based on our experimental data the mean  $F_{\max}$  for intact canine tibiae in the body weight range of 15–35 kg is  $8193.25 \pm 2082.84$  N. These baseline values are important for the purpose of future studies, so that optimal equipment settings may be used. To our knowledge, no scientific communication of this sort on canine tibiae was published to date. A testing velocity of  $50 \text{ mm min}^{-1}$  was applied. We found scarce information in the literature pertaining to testing velocity, however in a study that compared locking and non-locking orthopaedic implants and was performed on canine humeri, a velocity of  $5 \text{ mm min}^{-1}$  was used (Filipowicz et al., 2009). Lower testing velocities might contribute to fewer technical difficulties. However, we can assume that a testing velocity of  $50 \text{ mm min}^{-1}$  is adequate for our experiment.

In a total of four cases, tibiae slipped out of the testing device laterally without fracturing due to a mistake in clamping. Tibiae were then repositioned and subjected to repeated testing until failure. These cases were marked with an \* in Table 1. It was assumed that the cause of the malfunction of the clamping mechanism was due to the top and the bottom of the sample not being exactly parallel with each other. Therefore, accurate alignment of the top and bottom

ends of bones in the testing construct is of paramount importance, which will be addressed in future tests. The clamping on the bottom end was made from PMMA as it was described in other veterinary scientific studies (Aguila et al., 2005; Leitner et al., 2008; Filipowicz et al., 2009). Clamping of the top end was made from epoxy resin that is used similarly in human biomechanical research (Ali et al., 2003; Houskamp et al., 2020).

Statistical analysis of the results could not be performed. It is safe to conclude, however, that tibiae that underwent osteotomy of the tibial tuberosity and crest (Group 2) and tibiae that underwent TTA-rapid (Group 3) required less force to fracture as compared with intact tibiae (Group 1):  $6868.58 \pm 1950.44$  N,  $7169.71 \pm 4450.39$  N and  $8193.25 \pm 2082.84$  N, respectively. A final conclusion could not be drawn, but the results suggest that the procedures performed on Groups 2 and 3 lead to a significant weakening of the tibial construct.

The main limitations of our study were the low number of samples and the technical difficulties with bone clamping. In future studies, we are planning to increase the number of samples to 10 in each group. A further limitation, like in most biomechanical studies on cadavers, is the diversity of groups and that of the samples within each group. To help homogenise groups we limited body weight to 15–35 kg, and placed right and left tibiae of the same animal in different groups. In our study, tibiae were subjected to static loading. Cyclic loading, however, would better simulate forces acting on the limb during ambulation.

In conclusion, a tibia with a normal bone structure from a dog between 15 and 35 kg body weight will take an axial force of 8000–9000 N before fracturing. Moreover, surgical techniques used for CCL repair that include osteotomies of the tibial tuberosity and crest are likely to result in the weakening of the tibia. Further studies are needed to support this hypothesis.

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