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Mechanical resistance of the modified stabilization method for the tibial tuberosity advancement technique. *Ex vivo* experimental study in dogs

Resistência mecânica da técnica de avanço da tuberosidade tibial modificada: estudo experimental *ex vivo* em cães

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ABSTRACT

The present study aimed to evaluate a modification of the stabilization method of the tibial tuberosity advancement technique (TTA), originally described for stabilization of the cranial cruciate deficient stifle. Ten adult mongrel dogs with weights ranging from 25 to 30kg were used. After euthanasia, the hind-limbs were divided into two groups: G1 – test (n=10), and G2 - control (n=10) represented by the contra lateral limb. The test group was submitted to the modified TTA technique, stabilized by one shaft screw in craniocaudal position and a titanium cage inserted at the osteotomy site. The position of the patellar tendon, 90º in relation to the tibial plateau, and the correct position of all implants were confirmed radiographically after surgery. Posteriorly, in both groups, limbs were harvested and tibias collected with their respectively patellar tendon insertion preserved for the mechanical resistance test. The fixation of the tibial tuberosity with a shaft screw and titanium cage resulted in resistance compatible with the normal physiological forces transferred to the hind-limbs during locomotion. The biomechanical tests confirmed the viability of the method performed for the tibial tuberosity fixation and support future clinical trials to validate the technique.

Key words: *tibial tuberosity advancement, dog, cranial cruciate rupture, mechanical resistance.*

RESUMO

O presente estudo teve por objetivo avaliar a resistência mecânica do método de estabilização da técnica de avanço da tuberosidade tibial (TTA), originalmente descrita para tratamento da ruptura do ligamento cruzado cranial. Foram avaliados 10 cães, sem raça definida e com massa corporal entre 25 e 30kg. Após a eutanásia, os membros pélvicos foram divididos em dois grupos, sendo que G1 era o grupo teste (n=10) e G2 o controle (n=10), representado pelo membro contralateral. O grupo operado foi submetido à técnica de avanço da tuberosidade tibial (TTA) modificada, com emprego de um parafuso especial em posição craniocaudal e um espaçador de titânio inserido no local de osteotomia. O posicionamento do tendão patelar perpendicularmente ao platô tibial e o correto posicionamento dos implantes foi confirmado radiograficamente em todos os espécimes. Posteriormente, em ambos os grupos foram coletadas as tíbias, com preservação da inserção dos seus respectivos tendões patelares, para realização dos testes de resistência mecânica. A estabilização da tuberosidade tibial por parafuso especial em sentido craniocaudal e espaçador de titânio demonstrou resistência compatível com as forças fisiológicas tradicionalmente impostas ao membro pélvico durante a locomoção. Os testes biomecânicos confirmam a viabilidade do método de estabilização e sustentam estudos clínicos futuros para validação da técnica cirúrgica.

Palavras-chave: *avanço da tuberosidade tibial, cão, ligamento cruzado cranial, resistência mecânica.*

INTRODUCTION

The instability and degenerative joint disease caused by cranial cruciate ligament (CCL) rupture are well defined as frequent causes of pain and lameness of hind-limbs in dogs (CONZEMIUS et al.,

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2005). The development of surgical procedures that promote changes in the joint anatomy and biomechanics constitutes a new perspective to decrease osteoarthrosis progression and restore normal limb function (MONTAVON et al., 2002). The tibial plateau leveling osteotomy (TPLO) has been studied and used worldwide, especially in the United States and Europe, with promising results (CONZEMIUS et al., 2005; VEZZONI, 2006). Although cranial drawer movement is not eliminated, TPLO leads to the functional stability of the stifle joint during the stance phase of locomotion (WARZEE et al., 2001; REIF et al., 2002). Despite overall acceptance by most surgeons, studies using force plate analysis showed similar results in long-term outcome for the lateral suture technique and the Slocum TPLO (CONZEMIUS et al., 2005).

Tibial Tuberosity Advancement (TTA) was described as a new alternative for stabilizing the cranial cruciate deficient stifle (MILLER et al., 2007). According to the authors, the method promotes less alteration to the intraarticular and periarticular components, and therefore leads to superior clinical results (TEPIC, 2006). The technique is based on the comprehension of the internal and external forces acting on the stifle joint (GUERRERO, 2003). The contraction of the quadriceps and flexor muscle in the original joint results in a force whose vector is approximately parallel to the patellar tendon and cranially sloped in relation to the tibial plateau (MONTAVON et al., 2002). The biomechanical principle of the method consists of the neutralization of the cranial tibial thrust force by placement of the patellar tendon perpendicular to the tibial plateau (TEPIC, 2006). The new position is achieved by the osteotomy of the tibial tuberosity and insertion of a space cage in the defect, followed by stabilization with a special titanium plate fixed by fork and screws. It is necessary to emphasize however, that, like in Slocum's TPLO, both specialized training and acquisition of specific instruments are needed to perform TTA (MONTAVON et al., 2002). Recent studies report the exact biomechanical modifications after TTA on the stifle joint (APELT et al., 2007).

The present study evaluated, *ex vivo*, a modification method for stabilization of the tibial tuberosity advancement technique using a spacing cage inserted at the osteotomy site and a stainless steel shaft screw positioned in a craniocaudal direction from the tibial tuberosity. The hypothesis is that implants used for bone stabilization after tibial tuberosity advancement are of sufficient rigidity to support forces acting on the stifle joint during normal locomotion.

MATERIAL AND METHODS

1. Animals and experimentation groups

Ten male mongrel dogs, aged between 1.8 and 4.2 years (mean=3 years) and weighing 20 to 30kg (mean=27.8kg), euthanatized for reasons unrelated to this study and free of orthopedic disorders, were studied. Immediately after euthanasia, the limbs were numbered 1 to 10, according to the respective dog, and randomly divided into two groups: G1–test (n=10), and G2–control (not submitted to test; n=10) represented by the opposite limb.

2. Pre-operative plan and surgical procedure

The distance of the tibial tuberosity advancement was determined radiographically, after transection of the cranial cruciate ligament, in the mediolateral x-ray projection with the stifle extended 140^{o}. The patellar tendon was represented by a line from the distal patella to the proximal tibial tuberosity and the tibial slope determined by a line tangent to the cruciate ligament insertion points. The angle formed between the two lines determined the patellar tendon inclination. An acetate sheet with perpendicular lines in predetermined scale (6, 9 and 12cm) was laid up over the radiography using the patellar tendon and tibial plateau marks to determine the spacing cage size (MONTAVON et al., 2002).

The dog was placed in dorsal recumbency, slightly rotated to one side to allow a medial approach to the proximal half of the tibia and stifle joint. A medial parapatellar arthrotomy was performed followed by transection of the cranial cruciate ligament (CrCL). Afterwards, the tibial tuberosity was freed from soft tissue and a longitudinal osteotomy performed with an electric oscillating saw. The osteotomy started at the point between the tibial shaft and tuberosity and was directed proximally to a point cranial to the meniscus borders, avoiding the patellar tendon. An osteotome with width similar to the space cage was inserted at the osteotomy site to promote cranial and proximal translation of the tibial tuberosity. The previously determined space cage was inserted at the osteotomy site and fixed cranially and caudally with two self-tapping titanium screws (3.5mm in diameter), one in the tibial tuberosity and another in the caudal segment of the proximal tibia. The tibial tuberosity was stabilized with a stainless steel shaft screw (4mm of diameter) inserted distally to the spacing cage and oriented in a craniocaudal direction (Figure 1). To avoid iatrogenic fracture of the tibial tuberosity during hole drilling from the tibial tuberosity to the caudal cortex of the proximal portion of the tibia, drill bit sizes were sequentially

Figure 1 - Radiographic image of specimen 3 after the modified TTA technique. (a) mediolateral view, (b) craniocaudal view.

increased from 1.5 to 3.5mm in diameter. The drill hole was measured with a depth-gauge and an appropriate self-tapping screw used in lag fashion. Finally, transection of the semitendinous muscle tendon was performed to allow coverage of implants and bone defect. The crural fascia was closed by a simple interrupted pattern, the subcutaneous with a simple continuous pattern and skin using simple interrupted pattern.

3. Mechanical resistance of implants

After the surgical procedure, all limbs in both groups were harvested by hip disarticulation. Soft tissues were removed, thus preserving the patella and patellar tendon. The tibia was transected on its transverse axis 3cm proximal to the tarsocrural joint and the femur disarticulated in its distal extremity. The specimens were individually wrapped in moistened towels soaked in 0.9% saline, kept in plastic bags and frozen at -20°C. Prior to the mechanical tests, the specimens were allowed to thaw at room temperature for 24 hours.

Mechanical destruction was performed in both groups using a universal assay machine, with a load cell of 2000N and velocity of 50mm min^{-1}. The tibia was fixed in one of the extremities of the machine by 4.0mm Steinmann pins with length of 5cm, attached to a board, and the patella fixed at the other extremity by a special clamp device (Figure 2). The force necessary to disrupt each system was collected and graphically displayed. Also, for each specimen, the vertical peak force was estimated as 110% of body weight and used for comparison with the values obtained from the operated group (VIDA et al., 2005).The statistical analysis was performed by analysis of variance followed by Tukey test to evaluate the mechanical resistance of the implants. All data were considered significant if $P<0.05$.

RESULTS

The maximal load supported by specimens was 650N and 1625N, in groups 1 and 2, respectively. The estimated peak vertical force was 309N (Figure 3). There was evidence of deformation of the titanium screws used for fixation of the caudal portion of the spacing cage in specimens 1 and 7, and a discrete

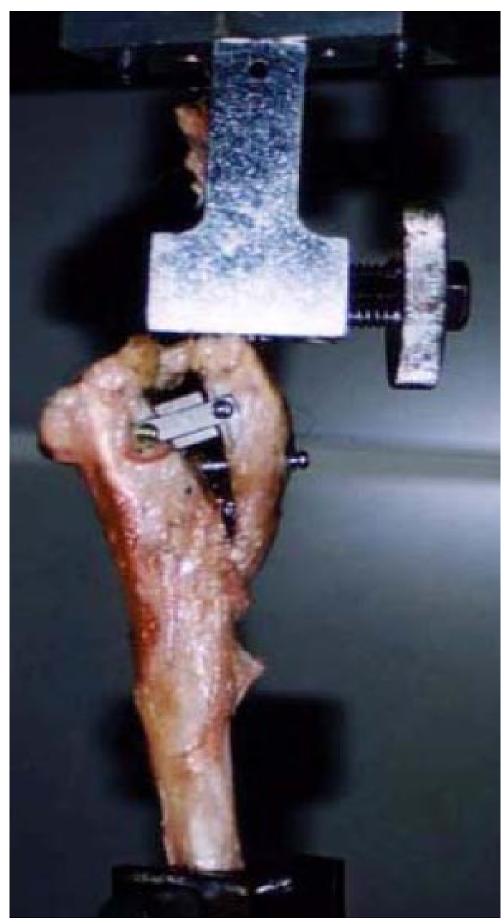

Figure 2 - Representation of Specimen number 3 placement before the mechanical resistance test.

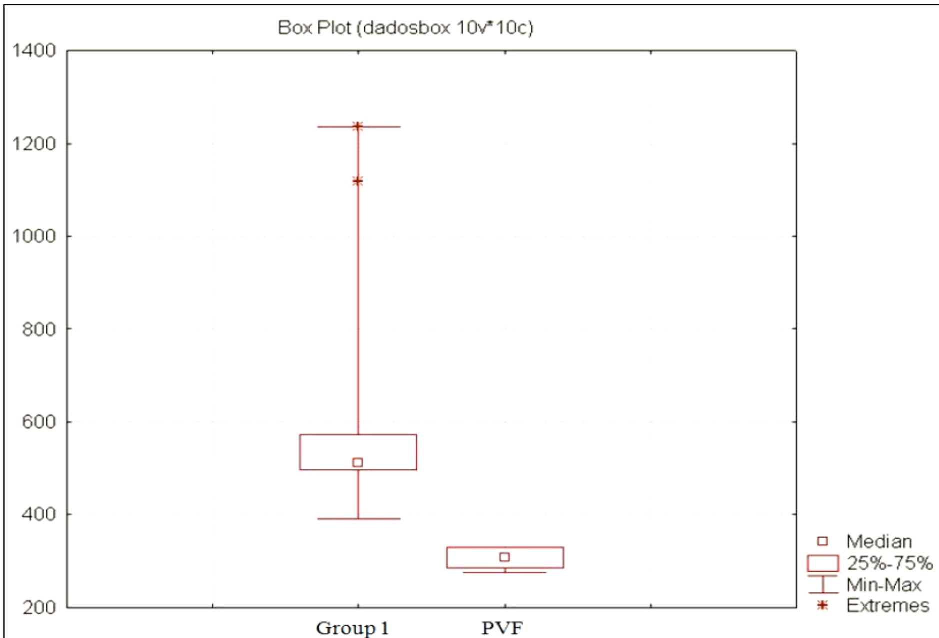

Figure 3 - Graphic representation of the statistical analysis of maximal load supported by specimens from group 1 (operated) and estimated peak of vertical force to the hind-limb (PVF).

deformation of the craniocaudal screw used to stabilize the tibial tuberosity in specimen number 6. Specimen 2 of group 1 had a short oblique diaphyseal fracture of the tibia. This limb presented a maximal load (46 N) that constituted a discrepancy from the rest of the group, and was excluded from the statistical analysis. The other nine specimens from group 1 showed avulsion of the tibial tuberosity on its point of contact with the tibial diaphysis, with displacement of the implants during traction.

DISCUSSION

The present study demonstrated that the proposed method of tibial tuberosity stabilization was capable of supporting forces compatible with the physiological moment-arm on the canine hindlimb during locomotion. The proposed modification in the technique was the replacement of the titanium plate and fork by one stainless steel screw, but with maintenance of a special spacing cage. Although much simpler than the original technique, the proposed modification requires special considerations. On the original TTA, the authors preclude the osteotomy in two steps to maintain bone alignment (GUERRERO, 2003). Initially, the distal osteotomy is performed, and after partial plate fixation, the osteotomy is completed in a proximal direction (MONTAVON et al., 2002). With the proposed alternative fixation system, according to the characteristics of implants, a one-step procedure seems necessary for the osteotomy. The use of a bone clamp to temporarily stabilize the tibial tuberosity during drilling and insertion of the craniocaudal screw allowed for maintenance of correct bone alignment. Also, to prevent iatrogenic fracture or fissure of the tibial tuberosity, the craniocaudal hole was drilled with progressively increasing bit diameters. This strategy permitted good results, since none of the limbs presented any sign of bone lesion during screw insertion. However, this can be a challenge in small dogs in spite of the increased risk of fissures of tibial tuberosity during perforation.

To determine the biomechanical viability of the modified TTA technique, results were compared to the physiological forces applied to the hind-limb (VIDA et al., 2005). Peak vertical force was estimated for the hind-limbs in all dogs, based on the body weight after euthanasia (BALLAGAS et al., 2004). Various studies showed that in healthy dogs, the hindlimb during locomotion achieves a force equal to approximately 100% of the body weight (CONZEMIUS et al., 2005). To perform the biomechanical evaluation in the present study, the authors considered the estimated force of the hindlimb to be 110% of body weight, indicating the minimum systemic resistance limit. These values allowed a good safety margin since peak vertical force is reduced in dogs with spontaneous CrCL rupture (BALLAGAS et al., 2004). The methodology described above is corroborated with various studies in a way to simulate the mechanical forces applied to stabilization methods and provides a reliable alternative to support future clinical trials (HULSE et al, 1997; HAERDI et al, 2003; KOWALESKI et al, 2003; LIPTAK et al, 2006).

The strength of specimens of group 1 (operated) was 40% of values obtained from group 2 (control). Despite the difference, all stifles in group 1 (test), except specimen 2, showed a maximal supported load (651±303N) superior to the estimated peak vertical force in the respective limb (309 ± 22 N). These results, compared with the estimated 1N/kg craniocaudal force imposed on the intact CrCL, confirmed the viability of the fixation of the tibial tuberosity by a craniocaudal screw and a space cage (INNES, 2006). The spacing cage transfers the force originated by the patellar tendon in the tibial tuberosity to the proximal tibia, and also promotes caudal support to the tibial tuberosity (TEPIC, 2006). Also, the fixation of the spacing cage by screws in the tibial tuberosity and in the caudal portion of the proximal tibia both contribute to the overall resistance.

The distraction test resulted in deformation of the fixation screw only in specimen number 6. This overall resistance can be attributed to two aspects. First, the screw inserted in a craniocaudal direction promoted a slight degree of interfragmentary compression and contributed to stabilization of the osteotomy. Second, shaft screws are more resistant and increase the bone contact compared with traditional cortical screws with threads throughout its length (ROE, 2003).

In the biomechanical study, the breaking point in the modified TTA technique corresponded to the tuberosity junction within the tibial diaphysis, since in nine specimens the proximal displacement of the tibial tuberosity occurred, with pullout of implants (craniocaudal screw and spacing cage). It is likely that the craniocaudal screw was not capable of supporting the increased traction load on the tibial tuberosity. Despite this, the total failure of the specimens only occurred with a load greater than the expected normal physiological forces applied to the hind-limb.

The most frequent complication related to TTA is tibial tuberosity fracture (MONTAVON et al., 2002), followed by intra-articular placement of cage screws and loosing of implants (HOFFMAN et al., 2007). None of the specimens evaluated with the modified tibial tuberosity presented signs of tibial tuberosity fracture or fissure. Probably, the craniocaudal screw does not weaken the bone integrity of tibial tuberosity. The tibial diaphysis fracture observed in specimen 2 might be associated with the placement of the tibial tuberosity osteotomy, which presented a proximal direction in a point caudal to the cranial borders of meniscus. This position is inadequate since it increases the possibility of meniscal damage and loss of the caudal articular support, and decreases the stiffness of the tibial diaphysis (MONTAVON et al., 2002).

The character of the present study merits some considerations. The use of cadavers precludes the normal forces derived from muscle contracture and may be related to some degree of instability observed after TTA. Also, freezing the specimens could contribute to decreasing the overall resistance of systems.

The principal advantage of the modification of the tibial tuberosity advancement technique is the simplicity of the configuration and placement of the implants. Otherwise, it can be challenging to use the technique in small dogs because of the risks of iatrogenic fracture of the tibial tuberosity.

CONCLUSION

The modified tibial tuberosity advancement technique was effective in neutralizing the cranial tibial thrust force after ex vivo cranial cruciate desmotomy. The biomechanical tests confirmed the viability of the method used for stabilization of the tibia tuberosity and support future clinical trials to validate the technique.

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ETHICAL COMMITTEE AND BIOSECURITY

The methods used during the development of the present study were approved by the Ethical Committee for Animal Experimentation of the School of Veterinary Medicine and Animal Science, São Paulo State University (UNESP – Botucatu) (Protocol number 109/2004).

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