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Tibial Plateau Leveling Osteotomy in Dogs: An *Ex Vivo* Comparative Study of Knee's Surrounding Structures Protection Methods*

Rodrigo Casarin Costa, Rafael Manzini Dreibi, Caroline Ribeiro de Andrade, Maria Eduarda Bastos Andrade Moutinho da Conceição, Thiago André Salvitti de Sá Rocha, Fabrício Singaretti de Oliveira, Bruno Watanabe Minto & Luís Gustavo Gosuen Gonçalves Dias

ABSTRACT

***Background*:** Cranial cruciate ligament failure is one of the leading causes of pelvic limb lameness in dogs and one of the most recommended treatments is tibial plateau leveling osteotomy (TPLO) surgery. However, this procedure may lead to some complications as fractures of the fibula, laceration in varying degrees of the popliteal vasculature and its branches, neuropraxia, neurotmeses, among others. The goals of this study were to compare the effectiveness of 8 methods used during TPLO, to prevent damage to the cranial tibial artery, fibula, tibial and fibular nerve (surgical compresses, specific surgical retractors I and II and an osteotomy technique variation).

***Materials, Methods & Results*:** A total of 40 canine cadavers weighing 25.9 ± 3.7 kg were submitted to TPLO. Animals were previously prepared with 1: 4 barium red latex solution, to provide radiopacity of arteries surrounding the knee (n = 80). TPLO was performed using 8 methods to protect the cranial tibial artery, fibula, and tibial and fibular nerves. Each method was used in one of the knees of 5 animals. The contralateral knee was maintained as a control (without protection). The knees were radiographed in orthogonal projections before and after the osteotomies and then anatomically dissected. The evaluated structures were photographed, and the images sent to four blind evaluators (visual macroscopy) to classify the possible injuries. The highest incidence of injuries was identified when protection methods were used. However, this difference was not significant ($P > 0.05$). No significant differences regarding efficacy were found between all 8 protection methods.

***Discussion*:** In this study, the total incidence of injuries following TPLO was 20% was much higher than that presented in the literature which indicates when considering only intraoperative injuries. The dogs cadavers tissue resistance and stiffened latex may have predisposed the osteotomy injury, as soft tissues with greater flexibility are less susceptible to trauma caused by the oscillatory saw. When compared to others cadaveric studies that also evaluated the efficacy of surgical dressings to protect the cranial tibial artery, during TPLO, we also find a higher incidence of damage. Maybe the limb's position was responsible for this difference, once in the after mentioned researches the limb was positioned suspended to simulate a dorsal decubitus position and we choose the limb position with the lateral face resting on the surface of the operating table, and this may have provided extra pressure from the structures towards the osteotomy saw, increasing the occurrence of those damages. Although the present study did not reveal a significant difference for the use of protection methods, we believe that the dimensions of the compresses used herein may have contributed to a higher incidence of injuries. They probably increased the tissue trauma needed for their allocation and led to a lower positioning accuracy for the isolation of these structures. Maybe for the same reason, the specific type II surgical retractor was the only shield that, observationally, did not increase the occurrence of injuries, once less dissection was required to allocate it. The difference in geometric dimensions between the retractors may justify the superiority of the retractor II, since it allows a more careful and apparently less traumatic allocation. Performing TPLO without adopting these protection methods did not lead to a higher risk of injury to the cranial tibial artery, fibula, and tibial and fibular nerves.

Keywords: osteotomy, vascular anatomy, canine stifle, TPLO.

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[1]Department of Veterinary Medicine and Veterinary Surgery, School of Agricultural and Veterinarian Sciences, São Paulo State University (Unesp), Jaboticabal, SP, Brazil. CORRESPONDENCE: L.G. Dias [gustavogosuen@gmail.com]. Department of Veterinary Medicine and Veterinary Surgery - Unesp. CEP 14884-900 Jaboticabal, SP, Brazil.

INTRODUCTION

Cranial cruciate ligament (CrCL) failure is one of the leading causes of pelvic limb lameness in dogs, causing pain and triggering degenerative joint disease [5,8]. Over the past 20 years, tibial plateau leveling osteotomy (TPLO) is one of most widely used and researched orthopedic procedure in veterinary medicine.

However, 10-34% of all TPLO procedures may lead to minor or major complications involving adjacent soft tissues, bone tissue, the implant, or a combination thereof. Some of the trans-operative complications include fractures of the fibula and laceration in varying degrees of the popliteal vasculature and its branches, such as the cranial tibial artery, neuropraxia, neurotmeses, among others [1,4,7,15].

The original TPLO technique uses surgical compresses between the tibia and the popliteal musculature in order to prevent damage to structures close to the knee [13]. Although this strategy does not appear to reduce the damages, so its effectiveness was contested with *in vivo* studies and angiographic analyzes of cadavers [3,12]. Despite surgical compresses seems not to be effective, other empiric used damage prevention methods have not yet been fully analyzed.

The goal of this study was to define and compare the effectiveness of 8 methods used during the execution of TPLO, to prevent damage to the cranial tibial artery, fibula, tibial and fibular nerve (surgical compresses and specific surgical retractors I and II created by our team used with different insertion ways).

MATERIALS AND METHODS

Subjects

A total of 40 canine cadavers (80 knees) with a body weight of 25.9 ± 3.7 kg were used. There was no predilection for breed, gender or age, but all selected animals were not previously diagnosed with conditions related to the knee. The cadavers were prepared with a solution of barium sulfate and colored latex (red) diluted in water (dilution 1: 1) in the proportion of 1: 4, at a dose of 15 mL/kg via catheterization of their carotid artery and then refrigerated at -20ºC for 48 h to solidify the solution.

Experimental design

The cadavers were randomly divided into 8 experimental groups of 5 animals. The experimental groups are listed in Figure 1. Both knees of each cadaver were submitted to osteotomy: the right knees were operated using one of the protection methods (Figure 2), while the left knees were operated without the use of protection methods (controls). Following this strategy, we aimed to reduce the influence of individual anatomical variations on the results.

Besides the compresses, we also tested specific surgical retractors created by our team, called type I and type II (Figures 1 & 3) These retractors present different shapes to provide greater protection area and fit the lateral surface of the proximal tibia (type I) and achieve a more delicate introduction and better accommodation into the lateral face of the proximal tibia (type II). We also used a modified osteotomy characterized by a partial osteotomy of the lateral (trans) cortical, with subsequent application of digital pressure to complete the separation of the bone fragments (Figure 2).

G1	Right knee - TPLO + craniolateral compresses Left knee - TPLO
G2	Right knee - TPLO + caudolateral compresses Left knee = TPLO
G3	Right knee - TPLO + craniolateral-caudolateral compresses Left knee - TPLO
G4	Right knee - TPLO + Surgical retractor I craniolateral Left knee - TPLO
G5	Right knee - TPLO + Surgical retractor I caudolateral Left knee - TPLO
G6	Right knee - TPLO with parcial osteotomy Left knee - TPLO
G7	Right knee - TPLO + Surgical retractor II craniolateral Left knee - TPLO
G8	Right knee - TPLO + Surgical retractor II caudolateral Left knee - TPLO

Figure 1. List of experimental groups (G1 to G8) of the canine specimens submitted to the TPLO technique with or without protection methods.

Surgical procedure

To position the protection methods on the craniolateral face of the proximal tibia, an incision of the cranial tibial muscle was performed in the tibia's crest. To place them into the caudolateral face, we made an incision in the insertion of the long digital extensor muscle in the caudal face of the proximal tibia.

The position of the limb was standardized by placing its lateral face resting on the surface of the surgical table. The osteotomy line was not stabilized with a plate and screws in order to avoid additional damage to the tissues and obstructing the assessment of the structures in the radiographic study by the overlapping of implants.

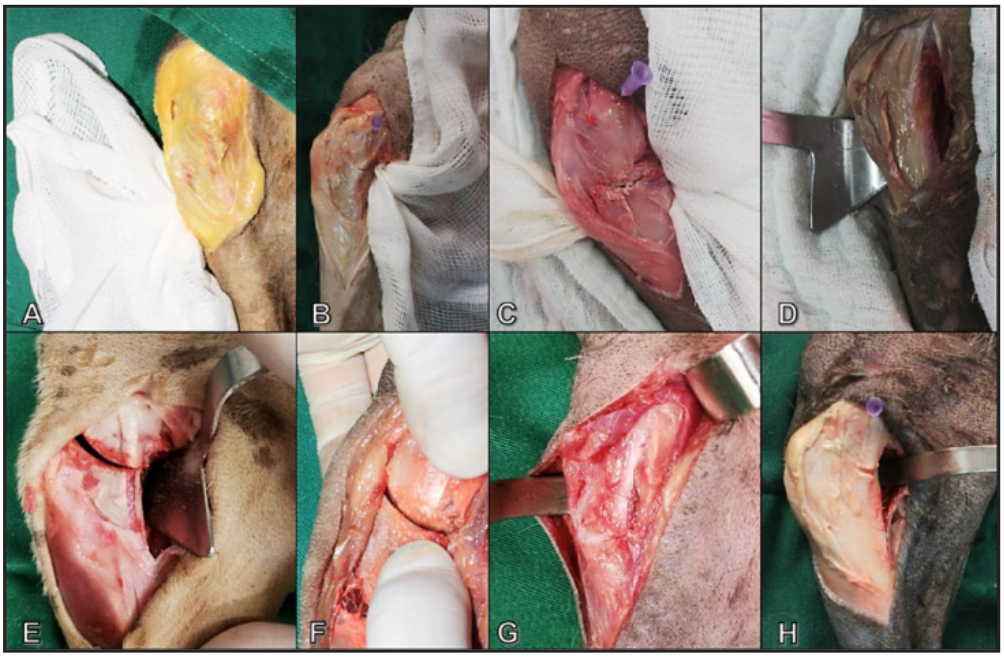


Figure 2. Photographic images of the medial face of the proximal tibia of canine cadavers during TPLO using 8 different methods to protect the structures of the lateral face of the proximal tibia. A- Using surgical compresses allocated on the craniolateral face (G1). B- Surgical compresses allocated on the caudolateral face (G2). C- Surgical compresses wrapping the entire lateral face, then introduced on the craniolateral face and pulled to the caudal face (G3). D & E- Using the specific surgical retractor I on the craniolateral (G4) and caudolateral (G5) surfaces, respectively. F- Modification of the technique by means of partial osteotomy of the transcortical, and subsequent digital pressure to conclude the fragment release (G6). G & H- Using the specific surgical retractor II allocated on the craniolateral face of the proximal tibia (G7) and the caudolateral face (G8), respectively.

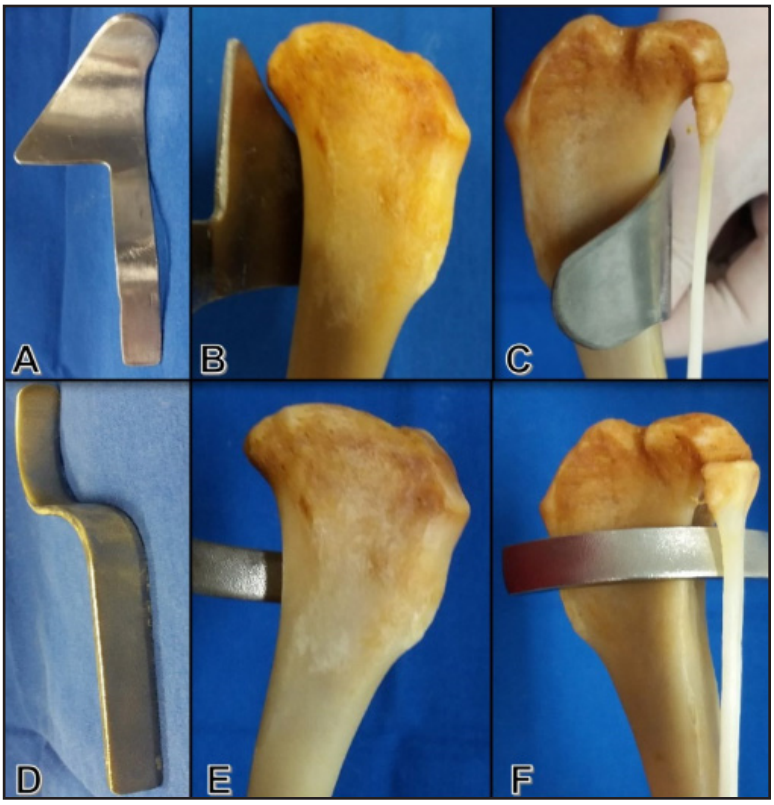


Figure 3. Photographic images of the specific surgical retractors type I (A-C) and II (D-F) for TPLO and its use in the left canine tibia model. A- Detail of the surgical retractor I. B & C- Allocation of the type I retractor in the caudocranial direction through the medial and lateral views, respectively. D- Detail of the surgical retractor II. E & F- Medial and lateral views of the type II retractor allocated in the caudocranial direction, respectively.

Data acquisition

To assess the integrity of the cranial tibial artery, fibula, and tibial and fibular nerves, we used visual macroscopic analysis by anatomical dissection after radiographic examination. Vasculature and bone tissue were also assessed by radiographs associated with arteriography before and after osteotomy.

To maintain the reliability of the results, specimens with structures lesioned by the dissection technique were excluded and replaced.

To better illustrate the structures, the radiographic and photographic images taken during the dissection were prepared with graphic elements before sent out to 4 evaluators blind as to the which knee and group was treated with the protection methods or not.

The possible damages observed in the structures analyzed were classified by the evaluators according to the extent of the injury.

For the tibial and fibular nerves and cranial tibial artery:

• Grade I - No damage;

• Grade II - Laceration of up to 50% of the structure's diameter.

• Grade III - Subtotal (more than 50%) or total rupture of the structure.

For the fibula:

• Grade I - No damage;

• Grade II - Osteotomy of a cortical \ Subluxation of the fibular head.

• Grade III - Dislocation of the fibular head / Osteotomy or fracture of 2 fibular cortices.

Data analysis

Statistical analyzes were performed with the help of the statistical software GraphPad Prism. Initially, the variation between the evaluators was analyzed using the Kruskal-Wallis test, the Dunn's post test, and the Bland-Altman agreement method. The variation between the evaluation methods, radiographic, and dissection were analyzed by the Mann Whitney and Bland-Altman tests to show whether the radiographic evaluation was reliable in detecting injuries to the cranial tibial artery and fibula. If the variation was not significant, the median of the evaluators for each studied variable attributed following dissection was used to compare the degree of injury found in the presence of each protection method in relation to their respective control (right knee vs. left knee). In this case we used the Wilcoxon-Mann-Whitney test. The degrees of injury between treatments (right knee vs. right knee for each of the methods) were analyzed using the Kruskal-Wallis test and Dunn's post test. The resulting values for each variable are presented as the median ± the interquartile range (IQR) while the variation between methods and evaluators are shown as bias ± standard deviation (SD). In all tests, significance was declared at 5% probability ($P \leq 0.05$).

RESULTS

As there was no statistically significant variation between the ratings assigned by the evaluators ($P > 0.05$), we calculated the median of the scores to obtain a single score for each of the structures evaluated, while maintaining the homogeneity of the results. Comparing the results obtained through radiographic evaluations with those obtained by dissection, revealed no statistically significant variation ($P > 0.05$) [Table 1]. Thus, only the results obtained through anatomical dissection will be presented (Figures 4 & 5).

Table 1. Median, interquartile range (IQR), and variation between radiographic and dissection methods

	Dissection		Radiographic evaluation		Bias	Bias' SD	*P*-valor
	Median	IQR	Median	IQR			
Cranial tibial artery	1	0	1	0	-0.05	0.31	0.54
Fibula	1	0	1	0	-0.06	0.12	0.99

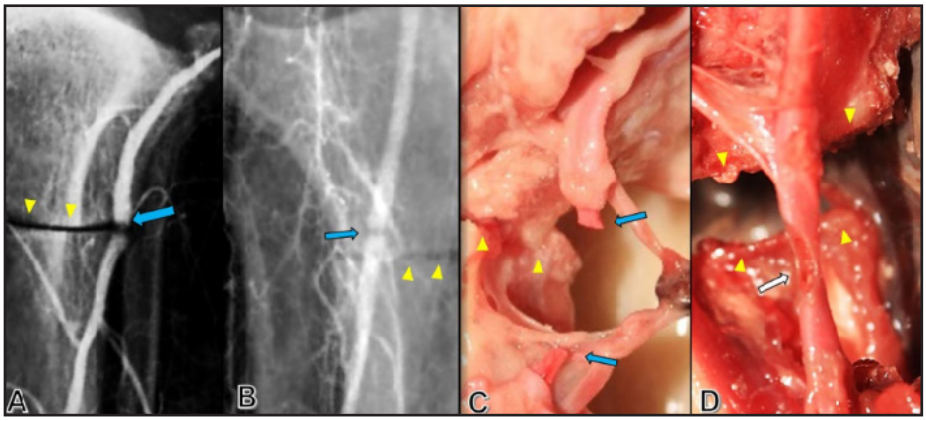


Figure 4. Radiographic images in mediolateral (A) and caudocranial (B) projections and photographic images (C & D) of a canine cadaver's left knee (without protection method) of the G2 group (using surgical compresses allocated on the caudolateral face of proximal tibia), submitted to TPLO (yellow arrowheads) illustrating possible injuries (blue and white arrows). A & B- Total interruption of the contrast line of the cranial tibial artery (blue arrow). C- Total laceration of the cranial tibial artery (blue arrows), identified by anatomical dissection. D- Partial lesion of the cranial tibial artery (white arrow) of the left knee of a specimen of the G4 group (TPLO only). All specimens were previously prepared with latex barium solution colored red for radiographic and anatomical identification of the cranial tibial artery.

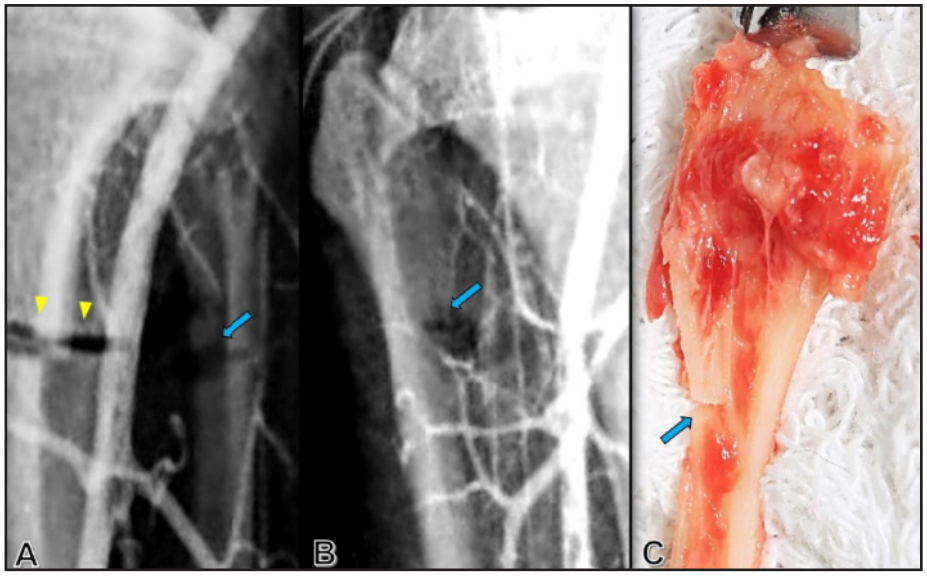


Figure 5. Radiographic images in mediolateral (A) and caudocranial (B) and photographic (C) projection of a canine cadaver's left knee (without protection method) belonging to the G4 group (specific surgical retractor type I allocated on the craniocaudal face of proximal tibial), submitted to TPLO (yellow arrowheads). A- Continuity lesion in the most cranial cortex of the fibula (blue arrow). B- Continuity lesion in the medial cortex of the fibula (blue arrow). C- Partial osteotomy of the fibula (blue arrow) of the same animal, identified by anatomical dissection. All specimens were previously prepared with latex barium solution colored red for radiographic and anatomical identification of the cranial tibial artery.

Although a greater number of injuries were observed when protection methods were used, the difference between protection and no protection was not significant ($P > 0.05$). The evaluated structures showed a rate of lesion incidence of 20% (Table 2), 15% of which were detected in the cranial tibial artery and 5% in the fibula (Table 3). No tibial and fibular nerve injuries were observed.

Analysis of the incidence of injury to the cranial tibial artery revealed a rate of injury occurrence of 12.5% in the groups G1, G2, G3, and G6 and a rate of 25% in the groups G4 and G7. A fibular injury rate of 25% was observed in the G2 and G4 groups, and a rate of 50% of injury occurrence was found in the G5 group. Despite of these observational differences, no statistically significant difference ($P > 0.05$) was found when we compared the protection methods with each other (right knee vs. right knee between the groups).

Table 2. Total incidence and classification of injuries to structures close to the lateral side of the knee of canine cadavers (n = 80 knees) submitted to TPLO using different protection methods (right knee) and their respective controls (without protection method; left knee).

Incidence of lesions						
Grade I		Grade II		Grade III		Total
0% (0/80)		13.8% (11/80		6.2% (5/80)		20% (16/80)
RK	LK	RK	LK	RK	LK	
0% (0/80)	0% (0/80)	81.8% (9\11)	18.2% (2\11)	60% (3/5)	40% (2/5)	

RK: Right Knee; LK: Left Knee. Grade I: No damage to cranial tibial artery, fibula and tibial and fibular nerves. Grade II: Laceration up to 50% of the cranial tibial artery and tibial and fibular nerves/ Subluxation of fibular head or a single fibular cortex osteotomy. Grade III: Total or subtotal damage (more than 50% of the diameter) of the cranial tibial artery and tibial and fibular nerves/ Luxation of fibular head or a total fibular osteotomy or fracture.

Table 3. Total incidence and classification of injuries to the cranial tibial artery and canine cadaver fibula (n = 80 knees) submitted to TPLO using different protection methods (right knee) and their respective controls (without protection method, left knee).

	Cranial tibial artery				Fibula	
RK	10% (8/80)	Grade I	0% (0/8)	5% (4/80)	Grade I	0% (0/4)
		Grade II	62.5% (5/8)		Grade II	100% (4/4)
		Grade III	37.5% (3/8)		Grade III	0% (0/4)
LK	5% (4/80)	Grade I	0% (0/4))	0% (0/80)	Grade I	0% (0/4)
		Grade II	50% (2/4)		Grade II	0% (0/4)
		Grade III	50% (2/4)		Grade III	0% (0/4)
Total	15% (12/80)			5% (4/80)		

RK: Right Knee; LK: Left Knee. Grade I: No damage to cranial tibial artery, fibula and tibial and fibular nerves. Grade II: Laceration up to 50% of the cranial tibial artery and tibial and fibular nerves/ Subluxation of fibular head or a single fibular cortex osteotomy. Grade III: Total or subtotal damage (more than 50% of the diameter) of the cranial tibial artery and tibial and fibular nerves/ Luxation of fibular head or a total fibular osteotomy or fracture.

DISCUSSION

In this study, the total incidence (with protection and control) of injuries following TPLO was 20%, a rate that is corroborated in the literature [1,4,7,9,15]. But considering only intraoperative injuries, this total incidence of injuries following TPLO was much higher than that presented in the literature which indicates 1 to 2% intraoperative injuries [6,14].

Direct comparison of our results with those presented in other retrospective clinical studies should be made with caution. Indeed, our study uses canine cadavers in which tissue resistance may be lower than the in vivo condition. In addition, stiffened latex may have reduced the flexibility of the artery, predisposing to osteotomy injury, as soft tissues with greater flexibility are less susceptible to trauma caused by the oscillatory saw [10-12].

Cadaveric studies that also evaluated the efficacy of surgical dressings to protect the cranial tibial artery, during TPLO using arteriography [12] and anatomical dissection [3], found no damage to the arterial structure. However, we found that this type of damage occurred in 15% of the animals. We believe that this difference is mainly due to limb's position, since in the aforementioned researches [3,12], the limb was positioned suspended to simulate a dorsal decubitus position. When the limb is maintained in a suspended position, the popliteal musculature relaxes and the cranial tibial artery is displaced caudally, that is, further away from the osteotomy line [11]. This strategy allows for a better perception of the moment when the osteotomy is completed [12]. In contrast, the position of the limb standardized in our study, with the lateral face resting on the surface of the operating table, may have provided extra pressure from the structures towards the osteotomy saw, increasing the occurrence of damages. As there are no studies comparing limb positioning during TPLO, most surgeons empirically position their patients according to their preference.

Although the present study did not reveal a significant difference for the use of protection methods, we believe that the dimensions of the compresses used

herein may have contributed to a higher incidence of injuries to the cranial tibial artery and fibula. They probably increased the tissue trauma needed for their allocation and led to a lower positioning accuracy for the isolation of these structures. The occurrence of trauma, following the use of protection methods, has also been noted by others when investigating the use of compresses [3,12]. There is evidence that compresses can release debris that cause tissue irritation, predisposing the site to infection [3] and increasing the risk of gossypiboma formation [2]. Further, the excessive dissection necessary to allocate the protective materials may damage the periosteal vascularization and hinder bone consolidation [2,3,11,12].

Our data reject the hypothesis that surgical retractors would produce better results than the control and other protection methods, at least in this study conditions (ex vivo study and limb position with its lateral face resting on the surface of the operating table. Nevertheless, even though there was no significant difference, the specific type II surgical retractor was the only shield that, observationally, did not increase the occurrence of injuries (group G8). This is probably because less dissection was required to allocate it when compared to the dissection extent required to allocate other protection methods. The difference in geometric dimensions between the retractors may justify the superiority of the retractor II, since it allows a more careful and apparently less traumatic allocation [2,3,11,12].

CONCLUSION

The present work serves as a basis for future clinical research regarding the effectiveness of methods for protecting the evaluated structures. Indeed, research using a larger number of knees and performed in live dogs maybe necessary to reach a more definitive evaluation. Thus, we recommend that the results of the present study should be used cautiously in the clinical routine since they were obtained using canine cadavers. We conclude that, in cadaveric dogs, the use of surgical compresses, specific retractors type I and II, and modified osteotomy does not guarantee protection to the popliteal artery, fibula, and tibial and fibular nerves during TPLO.

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***Ethical approval*.** This study was submitted to and approved by the ethics committee for the use of animals of the University of the State of Sao Paulo (Unesp), Jaboticabal, SP, Brazil, under protocol number 018973\17.

***Declaration of interest*.** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of paper.

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