

# Results of a survey of Veterinary Orthopedic Society members on the preferred method for treating cranial cruciate ligament rupture in dogs weighing more than 15 kilograms (33 pounds)

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## OBJECTIVE

To determine which method (lateral fabellotibial suture [LFS], tibial plateau leveling osteotomy [TPLO], tibial tuberosity advancement [TTA], or tight-rope-like braided multifilament suture secured with metallic buttons [TR]) Veterinary Orthopedic Society (VOS) members preferred for treating cranial cruciate ligament rupture (CCLR) in dogs weighing > 15 kg (33 lb), identify factors associated with this preference, and assess concerns related to surgical implant material used.

## DESIGN

Cross-sectional study.

## SAMPLE

187 VOS members.

## PROCEDURES

All registered VOS members received an online survey from June to July 2016. Responses were compiled and evaluated for associations with method preferences and perceived complications.

## RESULTS

Overall response rate was 38.4% (221/575). Respondents had graduated from veterinary school a mean of 23 years prior to survey completion, and collectively they performed approximately 30,000 CCLR surgeries annually. The most commonly preferred method was TPLO (147 [78.6%]), followed by TTA (26 [13.9%]), the LFS procedure (11 [5.9%]), and the TR procedure (3 [1.6%]). The preference for TPLO was independent of board certification or college of training (American, European, or other College of Veterinary Surgeons). Non-board-certified surgeons, including general practitioners, also favored TPLO. The most common perceptions were that titanium implants (used for TTA) were associated with the lowest incidence of major complications, whereas braided multifilament suture (used for the TR procedure) was associated with the highest incidence of major complications.

## CONCLUSIONS AND CLINICAL RELEVANCE

Results suggested that TPLO was preferred for treating CCLR in dogs weighing > 15 kg and that the TR procedure was perceived as having the highest complication rate. With results of this survey in mind, use of the TR procedure should be considered cautiously when treating CCLR. (*J Am Vet Med Assoc* 2018;253:586–597)

**C**ranial cruciate ligament rupture with subsequent joint instability is the most common pathological condition affecting the stifle joint of dogs.<sup>1</sup> In the United States, an estimated 1.7 million dogs underwent treat-

## ABBREVIATIONS

ACVS	American College of Veterinary Surgeons
CCL	Cranial cruciate ligament
CCLR	Cranial cruciate ligament rupture
ECVS	European College of Veterinary Surgeons
HTO	High tibial osteotomy
LFS	Lateral fabellotibial suture
TPLO	Tibial plateau leveling osteotomy
TR	Tight-rope-like braided multifilament suture secured with metallic buttons
TTA	Tibial tuberosity advancement
VOS	Veterinary Orthopedic Society of America

ment for this condition in 2005.<sup>2</sup> Although surgical stabilization is recommended for dogs weighing > 15 kg (33 lb),<sup>3,4</sup> the surgical method that provides the best outcome remains disputed.<sup>4–12</sup> The most commonly used methods for stabilization of CCL-deficient stifle joints (and the typically corresponding implant materials) in dogs are the LFS procedure (involving monofilament nylon suture),<sup>13–15</sup> TPLO (involving a 316L medical-grade stainless steel plate),<sup>16</sup> TTA (involving a titanium plate and cage),<sup>a</sup> and the TR procedure (involving multifilament braided strands of ultrahigh-molecular-weight long-chain polyethylene and polyesters, secured with metallic buttons<sup>b</sup>).<sup>8,c</sup> The TPLO and TTA methods are considered HTO procedures, whereas the LFS and TR procedures represent extracapsular procedures.

Although a consensus appears to exist among veterinary surgeons that surgical treatment of CCLR is beneficial for large dogs, the choice of a particular method in human and veterinary surgery is often based on surgeon's bias resulting from opinion or experience rather than on scientific evidence.<sup>17-19</sup> Furthermore, the abundance of conflicting information available online may contribute to client confusion regarding the choice of an optimal method for their dog, particularly if this choice conflicts with the surgeon's recommendation.<sup>20,21,d,e</sup>

Ideally, surgical method selection would be based on clinical evidence from direct clinical comparison of multiple methods for CCLR treatment. However, such evidence is lacking in large part because of logistical problems associated with the conduction of needed multicenter prospective studies. Alternatively, recommendations based on the collective, long-term experience of many veterinarians with practice limited to surgery might help reduce some of the confusion associated with the choice of a particular method and assist novice surgeons in their decision-making process. Indeed, in human medicine, a survey<sup>22</sup> of Major League Soccer team physicians helped identify their preferred surgical method for treating anterior cruciate ligament rupture.<sup>22</sup> For small animal surgery, members of the VOS would represent a similarly knowledgeable group of veterinary surgeons who commonly treat CCLR and could provide similarly useful information.

Minimal data have been collected in previous surveys<sup>4,19,23,24</sup> regarding preferred CCL repair methods. Although data on the LFS procedure, TPLO, and TTA have been compared in several studies, data on the TR procedure were included in only 1 study.<sup>4</sup> In addition, although descriptive statistics have been computed and reported, more detailed analysis has rarely been performed.<sup>19,23</sup> Furthermore, only 1 report<sup>19</sup> exists to provide data for medium-sized to large-breed dogs. Although encouraging outcomes had been achieved with the TR procedure in some studies,<sup>7,8,25-27,c</sup> its clinical preference was reported to be as low as 2% in a previous publication.<sup>4</sup> Lastly, to the authors' knowledge, no report exists comparing the complications associated with these 4 methods, and such information could be helpful in assisting veterinary surgeons in choosing the most appropriate treatment for CCLR in dogs.

The primary objectives of the study reported here were to determine which surgical method was preferred by a large group of veterinary surgeons (VOS members) when treating medium- to large-sized dogs with CCLR, which surgical implant material was perceived as associated with the highest or lowest incidence of major complications, and which factors might influence the choice of CCL repair method. Furthermore, we wanted to review the veterinary literature with focus on concerns identified for each method. Given existing anecdotal information and previous survey findings, our hypotheses were that

HTO procedures would be preferred to extracapsular procedures and perceived as having the lowest incidence of major complications, titanium implants would be perceived as associated with the lowest incidence of major complications, and board-certified veterinary surgeons would favor HTO procedures, compared with general practitioners with a strong interest in surgery but without residency training and non-board-certified surgeons, who would favor extracapsular procedures.

## Material and Methods

### Sample and survey

Two preliminary surveys were initially developed and tested on a total of 105 respondents, all of whom were board-certified veterinary surgeons or small animal veterinarians with a strong interest in orthopedics, including board members of the VOS. All these test respondents worked in academic institutions or private practice. They provided feedback that was used to produce a final survey to collect data on surgeons' preference and associated rationale regarding 4 surgical methods for treating CCLR in dogs weighing > 15 kg (**Supplementary Appendix S1**, available at [avmajournals.avma.org/doi/suppl/10.2460/javma.253.5.586](http://avmajournals.avma.org/doi/suppl/10.2460/javma.253.5.586)). The final survey asked that respondents indicate the approximate number of dogs with CCLR they treated per year; whether they were a board-certified surgeon, surgeon with complete residency training but no board certification, or non-board-certified surgeon (including general practitioners and surgeons with incomplete residency training and no board certification); college in which they were trained; number of years elapsed since graduation from veterinary school; field in which they primarily worked; preferred CCL repair method and the rationale for this choice; and their experience with each surgical method. In addition, they were asked to identify which repair methods and surgical implant material they expected would carry the highest and lowest incidence of major complications (defined as needing any medical treatment for > 4 weeks or any additional surgical treatment when performed by an experienced small animal surgeon [residency or ≥ 6 years of experience in orthopedic surgery]). Surgical implant materials associated with each CCL repair method in the survey were monofilament nylon suture (LFS procedure), medical-grade stainless steel plate (TPLO), titanium implant (TTA), and multifilament braided suture strands of ultrahigh-molecular-weight long-chain polyethylene and polyester with metallic buttons<sup>b</sup> (TR procedure).

Participants were also asked to identify up to 4 of 8 predefined factors (ie, infection, implant failure, secondary meniscal tear, unsatisfactory short- and long-term outcomes, owner dissatisfaction, "complications overall," and financial reasons) they experienced or perceived as related to a particular method that led to their discontinuing or never using that

method. For questions requiring numeric responses such as number of dogs or years elapsed, participants were asked to respond by entering single numbers and not ranges. For all other questions, participants were asked to select from specific options.

The board of the VOS supported the study and permitted use of their membership database to obtain contact information on its members, all of whom were sent email invitations to participate. Four invitations were sent electronically at intervals of approximately every 10 days from June 2016 to July 2016. The study was also announced to all registrants at the 2016 annual meeting of the VOS. Participation was voluntary and anonymous. To be included in the final analysis, survey respondents were required to have performed primarily small animal surgery, to consent to participate in the study, and to fully complete the survey. Failure to meet any of these criteria resulted in exclusion.

## Literature review

In addition to collection of survey data, the veterinary literature that existed at the time the study was performed was reviewed and summarized in relation to what was deemed to be the most important factors associated with each of the 4 CCL repair methods, including complications.

## Statistical analysis

Descriptive statistics were calculated to summarize the survey responses. The  $\chi^2$  test and, when necessary (owing to low numbers of certain responses), the Fisher exact test were used to test the study hypotheses. Respondent characteristics (board certification [yes or no]; completed residency but not board certified [yes or no]; college of training [ACVS, ECVS, other, or none]; and current field of work [private practice, academia, or research]) were evaluated for associations with method-related factors (preferred CCL repair method as well as methods and surgical implant materials with highest and lowest perceived incidence of major complications). All analyses were performed with statistical software.<sup>f</sup> Values of  $P < 0.05$  were considered significant.

## Results

### Survey

Email invitations for survey participation were sent to a total of 575 VOS members, and 221 surveys were returned, for an overall response rate of

38.4%. Thirty-four (15%) surveys were incomplete and therefore excluded. Data from the remaining 187 fully completed surveys were included in the analysis.

## Respondents

The mean  $\pm$  SD number of CCLRs surgically treated per year per respondent was  $159 \pm 113$  (range, 5 to 600), for a total of approximately 30,000 procedures performed/187 surgeons/y. Regarding education status, most respondents were board-certified veterinary surgeons ( $n = 142$  [75.9%]), surgeons with complete residency training but not board certified (16 [8.6%]), and surgeons with no complete residency training or board certification (29 [15.5%]; 26 general practitioners and 3 people who had started a residency with the ACVS but never completed it and thus were not board eligible). Overall, 161 of 187 (86.1%) respondents answered they had trained with a college of veterinary surgery. Most (143/161 [88.8%]) were trained with the ACVS, followed by the ECVS (8 [5.0%]) and other colleges (10 [6.2%]).

The mean  $\pm$  SD and median (range) number of years since graduation from veterinary school was  $23 \pm 12$  and 23 (0 to 56), respectively. The primary field in which most respondents worked was private practice (146 [78.1%]), followed by academia (40 [21.4%]) and then research (1 [0.5%]).

## Preferred CCL repair method

The CCL repair method most commonly identified by respondents as their preferred method was TPLO (147 [78.6%];  $P < 0.001$ ), followed by TTA (26 [13.9%]), the LFS procedure (11 [5.9%]), and the TR procedure (3 [1.6%]). The most common reason given for their choice of preferred method was high surgeon satisfaction for TPLO, the LFS procedure, and TTA (**Table 1**). For the 3 respondents who chose the TR procedure as their preferred method, high surgeon and client satisfaction and cost-effectiveness were selected equally (100% for all). The most common reason for not using each method was financial concerns for TPLO, implant failure for the LFS procedure, overall complications for TTA, and infections for the TR procedure (**Table 2**).

## Perception of safety

The CCL repair method most commonly chosen as having the highest incidence of major complications was the TR procedure ( $n = 81$  [43.3%]),

**Table 1**—Reasons indicated by VOS members ( $n = 187$ ) for their choice of preferred method for treating CCLR in dogs weighing  $> 15$  kg (33 lb).

Reason	LFS procedure (n = 11)	TPLO (n = 147)	TTA (n = 26)	TR procedure (n = 3)
High surgeon satisfaction	12 (100)	141 (97)	25 (96)	3 (100)
Cost-effective	9 (75)	32 (22)	6 (23)	3 (100)
High client satisfaction	9 (75)	96 (66)	14 (54)	3 (100)

Data represent number (%) of respondents who selected the indicated method as preferred. Respondents could select  $> 1$  reason.

followed by the LFS procedure (46 [24.6%]), TTA (41 [21.9%]), and TPLO (19 [10.2%];  $P < 0.001$ ). The method most commonly chosen as having the lowest incidence of major complications was TPLO ( $n = 112$  [59.9%]), followed by the LFS procedure (50 [26.7%]), TTA (20 [10.7%]), and the TR procedure (5 [2.7%];  $P < 0.001$ ). Braided multifilament suture material was the most common choice of surgical implant materials perceived as having the highest incidence of major complications ( $n = 161$  [86.1%]), followed by monofilament suture material (18 [9.6%]), medical-grade stainless steel implants (7 [3.7%]), and medical-grade titanium implants (1 [0.5%];  $P < 0.001$ ). Medical-grade titanium implants were the most common choice for having the lowest incidence of major complications ( $n = 103$  [55.1%]), followed by medical-grade stainless steel implants (51 [27.3%]), monofilament suture material (29 [15.5%]), and braided suture material (4 [2.1%];  $P < 0.001$ ).

### Board-certification status

A significant ( $P = 0.002$ ) association was identified between surgeon board-certification status and preferred CCL repair method, with the highest proportion of board-certified veterinary surgeons (121/142 [85.2%]) preferring TPLO over other methods (Table 3). A significant ( $P = 0.01$ ) association was

also identified between board-certification status and the method perceived as having the highest incidence of complications, with board-certified veterinary surgeons most often indicating the TR procedure (69/142 [48.6%]) over other methods (Table 4). A greater percentage of non-board-certified surgeons, including general practitioners with a strong interest in surgery but without residency training or board certification, also preferred TPLO over other methods, although this relationship was not significant.

### College training

A significant ( $P = 0.01$ ) association was identified between college training and preferred CCL repair method, with the highest percentage of ACVS-trained surgeons (125/143 [87.4%]) preferring TPLO over other methods but also with surgeons trained by the ECVS (5/8 [62.5%]) or other colleges (6/10 [60%]) preferring TPLO as well (Table 5). A significant ( $P = 0.01$ ) association was identified between college of training and perception of the surgical method with the lowest incidence of major complications, with 67.1% (96/143) of ACVS-trained respondents selecting TPLO. In contrast, ECVS-trained respondents selected both the LFS procedure and TPLO (each 3/8 [37.5%]) as having the lowest incidence of major complications (Table 6).

**Table 2**—Reasons indicated by the respondents in Table 1 for not using a specific method for CCLR repair.

Reason	LFS procedure (n = 11)	TPLO (n = 147)	TTA (n = 26)	TR procedure (n = 3)
Infections	9 (5)	12 (6)	19 (10)	107 (57)
Implant failure	119 (64)	6 (3)	34 (18)	56 (30)
Secondary meniscal tears	35 (19)	9 (5)	70 (37)	17 (9)
Unsatisfactory short-term outcome	112 (60)	1 (1)	26 (14)	54 (29)
Unsatisfactory long-term outcome	116 (62)	5 (3)	60 (32)	71 (38)
Owners unsatisfied	45 (24)	2 (1)	18 (10)	22 (12)
Complications overall	37 (20)	19 (10)	75 (40)	80 (43)
Financial concerns	4 (2)	24 (13)	29 (16)	20 (11)

See Table 1 for key.

**Table 3**—Preferred method for CCLR repair as indicated by the respondents in Table 1, according to education status.

Status	LFS procedure	TPLO	TTA	TR procedure
Board-certified veterinary surgeon (n = 142)	4 (2.8)	121 (85.2)	16 (11.3)	1 (0.7)
Residency training completed, but no board certification (n = 16)	2 (12.5)	12 (75.0)	2 (12.5)	0 (0)
No complete residency training or board certification (n = 29)	5 (17.2)	14 (48.3)	8 (27.6)	2 (6.9)
<b>Total (n = 187)</b>	<b>11 (5.9)</b>	<b>147 (78.6)</b>	<b>26 (13.9)</b>	<b>3 (1.6)</b>

Data represent number (%) of respondents with the indicated education status who selected the indicated method.

**Table 4**—Method for CCLR repair indicated by the respondents in Table 1 as having the highest incidence of major complications, according to educational status.

Status	LFS procedure	TPLO	TTA	TR procedure
Board-certified veterinary surgeon (n = 142)	35 (24.6)	8 (5.6)	30 (21.1)	69 (48.6)
Residency training completed but no board certification (n = 16)	4 (25.0)	3 (18.8)	4 (25.0)	5 (31.2)
No complete residency training or board certification (n = 29)	7 (24.1)	8 (27.6)	7 (24.1)	7 (24.1)
<b>Total (n = 187)</b>	<b>46 (24.6)</b>	<b>19 (10.2)</b>	<b>41 (21.9)</b>	<b>81 (43.3)</b>

See Table 3 for key.

**Table 5**—Preferred method for CCLR repair as indicated by the respondents in Table 1, according to source of college training.

College	LFS procedure	TPLO	TTA	TR procedure
ACVS (n = 143)	6 (4.2)	125 (87.4)	11 (7.7)	1 (0.7)
ECVS (n = 8)	0 (0)	5 (62.5)	3 (37.5)	0 (0)
Other college of veterinary surgeons (n = 10)	0 (0)	6 (60.0)	4 (40.0)	0 (0)
<b>Total (n = 161)</b>	<b>6 (3.2)</b>	<b>136 (72.7)</b>	<b>18 (9.6)</b>	<b>1 (0.5)</b>

Data represent number (%) of respondents with the indicated college who selected the indicated method.

**Table 6**—Method for CCLR repair indicated by the respondents in Table 1 as having the lowest incidence of major complications, according to source of college training.

College	LFS procedure	TPLO	TTA	TR procedure
ACVS (n = 143)	33 (23.1)	96 (67.1)	11 (7.7)	3 (2.1)
ECVS (n = 8)	3 (37.5)	3 (37.5)	2 (25.0)	0 (0)
Other college of veterinary surgeons (n = 10)	2 (20.0)	3 (30.0)	4 (40.0)	1 (10.0)
<b>Total (n = 161)</b>	<b>38 (23.6)</b>	<b>102 (63.4)</b>	<b>17 (10.6)</b>	<b>4 (2.5)</b>

See Table 5 for key.

**Table 7**—Preferred method for CCLR repair as indicated by the respondents in Table 1, according to field of work.

Field	LFS procedure	TPLO	TTA	TR procedure
Academia (n = 40)	2 (5.0)	35 (87.5)	3 (7.5)	0 (0)
Private practice (n = 146)	8 (5.5)	112 (76.7)	23 (15.8)	3 (2.1)
Research (n = 1)	1 (100)	0 (0)	0 (0)	0 (0)
<b>Total (n = 187)</b>	<b>11 (5.9)</b>	<b>147 (78.6)</b>	<b>26 (13.9)</b>	<b>3 (1.6)</b>

Data represent number (%) of respondents in the indicated field of work who selected the indicated method.

## Field of work

A significant ( $P = 0.04$ ) association was identified between current field of work and preferred CCL repair method. The highest proportion of respondents from both academia (35/40 [87.5%]) and private practice (112/146 [76.7%]) preferred TPLO over other methods (Table 7).

## Discussion

In the present study, the opinions of a cohort of 187 veterinary orthopedic surgeons were collected. They collectively performed approximately 30,000 CCL repair surgeries annually, had graduated from veterinary school at a mean of > 20 years previously, and thus had been exposed to CCLR for at least the same period prior to completing this survey. Most (78.6%) respondents selected TPLO as their preferred method for CCL repair for a dog weighing > 15 kg. This number reached 87.5% when considering only surgeons from academic institutions. Tibial tuberosity advancement was preferred by 13.9%, the LFS procedure by 5.9%, and the TR procedure by 1.6% of all respondents. No surgeons working in academia or research chose the TR procedure as their preferred method. These results supported our hypotheses that HTO procedures were preferred for treatment of CCLR in dogs and that an osteotomy method as well as the use of titanium implants was perceived as associated with the lowest incidence of major complications.

The hypothesis that board-certified veterinary surgeons would favor HTO procedures (TPLO and TTA), whereas non-board-certified surgeons, including general practitioners, would prefer extracapsular procedures (LFS and TR), was refuted in part: although TPLO was preferred by 85.2% and TTA by 11.3% of board-certified veterinary surgeons, these methods were also preferred by 48.3% and 27.6% of non-board-certified surgeons, including general practitioners. Non-board-certified surgeons, including general practitioners, also preferred an HTO procedure over the LFS (17.2%) and TR (6.9%) procedures, and so the hypothesis that these surgeons would prefer extracapsular methods was not supported. Although most respondents were board-certified veterinary surgeons and had been trained during their residency to perform osteotomies, we believe it noteworthy that, in this study, general practitioners with strong interest in surgery but without residency training or board certification also selected an HTO procedure as their preferred method, even though postgraduate training is recommended to learn such procedures.

The LFS method for CCL repair has been associated with high success rates over the past 4 decades (80% to 90% good or excellent results).<sup>11,14,15,19,28</sup> In a survey<sup>23</sup> focused on treatment of dogs with CCLR and weighing < 15 kg, LFS was the preferred method for 63% of respondents.<sup>23</sup> By contrast, our study focused on dogs > 15 kg, and LFS was preferred by only

5.9% of respondents. Although the main reason for this preference was high surgeon satisfaction, high client satisfaction and cost-effectiveness were also reported. Interestingly, cited reasons for not using the LFS procedure were implant failure and unsatisfactory long-term outcome. The LFS procedure relies on long-term periarticular fibrosis to provide long-term stabilization of the stifle joint,<sup>29</sup> and high (vs low) body weight has been associated with insufficient fibrosis to achieve the needed amount of stabilization in previous studies.<sup>15,30,31</sup> Indeed, in 1 study,<sup>10</sup> a persistent palpable drawer sign, likely due to insufficient fibrosis and stretching or breakage of the implant material, was identified in 15% of dogs treated by the LFS procedure > 12 months after surgery. Such instability could increase the risk of meniscal tear and osteoarthritis.<sup>15</sup> These previously reported findings could explain the perceived unsatisfactory long-term outcome associated with the LFS procedure for respondents in the present study.

Although the perception that the LFS procedure has an unsatisfactory long-term outcome is supported by findings from several clinical comparative studies,<sup>10,15</sup> a study<sup>11</sup> involving comparison of the LFS procedure with TPLO and an intracapsular technique revealed comparable outcomes between the LFS procedure and TPLO. In that study,<sup>11</sup> however, no randomization of patients was performed, and post-operative physical rehabilitation protocols were not standardized for all techniques, possibly influencing the results. In other, more recent research,<sup>10</sup> 75% of owners of LFS-treated dogs were satisfied with the outcome, compared with 93% of owners of TPLO-treated dogs. In another study,<sup>32</sup> orthopedic function of dogs following TPLO was indistinguishable from that of orthopedically normal dogs during long-term follow-up, unlike dogs treated by the LFS procedure, which never returned to normal orthopedic function. The most thorough comparative clinical study<sup>9</sup> of the LFS procedure, TTA, and TPLO to date revealed that only dogs treated by TPLO returned to normal orthopedic function. These findings support our results, which indicated that most of the surveyed veterinary surgeons preferred TPLO over the LFS procedure for dogs weighing > 15 kg.

In the study reported here, TPLO was not only the preferred method overall, but also the preferred method independent of the college of surgeon training. It was the method perceived to be associated with the lowest incidence of complications by both ACVS and ECVS diplomates. Tibial plateau leveling osteotomy was also the preferred method regardless of whether respondents worked in academia or private practice. The main reasons TPLO was preferred included perceived high client and surgeon satisfaction (66.2% and 97.2%, respectively). These preferences for TPLO mirror the results of numerous clinical studies<sup>9,32-37</sup> regarding outcomes following TPLO. Reasons cited for not using TPLO included financial concerns (12.8%) and overall complications (10.2%).

Although the perceived high financial cost of TPLO has been anecdotally derided in the media,<sup>38,39</sup> internal data from our practice<sup>8</sup> suggest that implant prices for non-LFS procedures may vary with size of implant, but they are in general fairly similar (implant alone: approx \$240 for the TR procedure, \$250 to \$500 for TPLO, and \$300 to \$360 for TTA). However, implants represent only a small part of the overall cost associated with a given procedure, and such costs differ widely among hospitals. Indeed, in addition to the surgeon's fee, various other items, such as imaging, bone grafting (with TTA), arthroscopy, anesthesia, and hospitalization, contribute to overall cost. Given existing data regarding long-term outcome of the LFS procedure versus TPLO and TTA<sup>9</sup> and the reported need to revise a procedure involving LFS<sup>h</sup> or advancement of the tibial tuberosity<sup>i</sup> with TPLO, TPLO might be the most financially appropriate choice in the long term.

Complication rates associated with TPLO in dogs reportedly range from 10% to 34%, with lower rates in more recent studies<sup>34,35,37,40</sup> in which TPLO was performed by a single or a few highly experienced surgeons and with improvements in implants and technique, and higher rates in earlier studies<sup>41-44</sup> when this procedure was first introduced or when studies involved numerous surgeons (including surgeons in training). Indeed, in the largest study<sup>36</sup> of complications associated with TPLO, which involved 1,519 procedures performed by experienced board-certified veterinary surgeons or veterinarians limited to the practice of surgery (residency trained but not board certified),<sup>36</sup> complication rates were substantially lower than those in the earlier reports on TPLO outcomes, at 3.1% and 8.3% for major and minor complications, respectively. Importantly, these complication rates were lower when compared with those for the TR and LFS procedures and TTA.<sup>8,15,45-47</sup> Although 0.8% of dogs undergoing TPLO in that study<sup>36</sup> sustained secondary meniscal tears, the incidence of that complication differed by whether meniscal release had been performed during initial surgery. Indeed, secondary meniscal tears were identified in 1.75% of 457 dogs that had not undergone meniscal release and in 0.66% of 452 dogs that had undergone meniscal release.<sup>36</sup>

The topic of meniscal release remains controversial,<sup>48</sup> given that in vitro research shows that this procedure (vs no meniscal release) may be associated with greater stifle joint instability and greater femoro-tibial contact pressures<sup>49,50</sup> and, on the basis of 5 dogs in 1 study,<sup>51</sup> may result in a greater degree of osteoarthritis. This previous research is often used as reference to suggest that meniscal release should not be performed. Indeed, in a previous survey<sup>4</sup> of ACVS diplomates and primary care veterinarians on CCLR treatment preference, meniscal release was not performed by most respondents. However, failure to perform meniscal release could lead to an increased amount of secondary meniscal tears, often resulting in persistent lameness requiring a revision surgery.<sup>48,52</sup>

Tibial tuberosity advancement was perceived as associated with a high incidence of secondary meniscal tears by the respondents of the present study. Indeed, 37.4% of respondents cited this as a reason for not using TTA. Secondary meniscal tears following TTA have been identified in 6.3% to 29% of treated dogs<sup>46,52-58,j,k</sup> and were identified in 50% of dogs in a prospective study<sup>l</sup> in which TTA was compared with TPLO. One explanation for this high rate of secondary meniscal tears could be persistent cranial tibial translation, detected in 70% of dogs treated by TTA in 1 study,<sup>59</sup> suggesting inadequate stability. Interestingly, another study<sup>58</sup> showed that meniscal release, which was performed in 72% of dogs treated for CCLR by TTA, was associated with only a 0.5% incidence of secondary meniscal tears, whereas the need for surgical management of this complication was as high as 10.2% when meniscal release was not performed with TTA. Similar findings were obtained in another study,<sup>46</sup> in which meniscal release with TTA reduced the rate of revision surgery from 27% to 2.5%.

Given findings from the 2 largest clinical studies<sup>36,58</sup> on TPLO and TTA to date, meniscal release (vs no meniscal release) appears to be associated with a reduced incidence of secondary meniscal tears with these methods. Notably, although the secondary meniscal tear rate remains higher with both TTA (10.2%)<sup>58</sup> and TPLO (1.75%)<sup>36</sup> when release of an intact meniscus is not performed, the large difference in the incidence of secondary meniscal tears between the 2 procedures suggests better stifle joint stability following TPLO.

Overall complications were also cited as a reason for not using TTA in the present study, as indicated by 40.1% of respondents. Although the reported rate of complications associated with TTA varies widely from 11% to 59%,<sup>45,46,52-56,60-64</sup> major complications were found in 13.4% of 1,613 dogs in the largest retrospective study<sup>58</sup> on TTA to date. However, minor complications were not reported, and thus the investigators surmised that the overall incidence of complications following TTA was likely underestimated.<sup>58</sup> Importantly, when the 2 largest retrospective studies on TTA and TPLO are compared, the complication rate following TTA appears > 3 times (13.4%)<sup>58</sup> that following TPLO (3.1%).<sup>36</sup> In contrast, only giant-sized dogs weighing > 50 kg (110 lb) were evaluated in another study<sup>65</sup> comparing 91 TTA and 54 TPLO procedures, revealing no significant differences in complication rates between methods. However and importantly, in that study,<sup>65</sup> 6% of TTA procedures required revision surgery to treat tibial tuberosity fractures, whereas no TPLO procedures required revision surgery. Surgical site infections were the main concern for both methods. Nonlocking TPLO plates were also used, and such plates have been associated with an increase in the postoperative infection rate.<sup>66</sup> Antimicrobial administration reduced the risk of infection in all treated dogs, regardless of method,<sup>65</sup> confirming the protective effect of antimicrobials against surgical site infection when administered following TPLO.<sup>35</sup>

Overall, 55.1% of respondents in the present study considered the use of titanium implants (used in most current TTA implants) as carrying the lowest risk of major complications of all surgical implant materials listed, and only 10.2% of respondents cited infection as a reason for not using TTA. This subjective assessment was supported by studies<sup>67,68</sup> that have shown lower infection rates associated with the use of implants made of titanium versus medical-grade stainless steel. Reported benefits of titanium implants over stainless steel implants include better antimicrobial activity, decreased bacterial adhesion, and high biocompatibility. Furthermore, their microrough surface allows titanium implants to tightly adhere to surrounding tissues, reducing the risk of biofilm formation.<sup>67,69</sup>

One retrospective study<sup>7</sup> showed that clinical outcomes and complication rates following TTA are inferior to TPLO and the TR procedure. Consequently, one might have anticipated that the TR procedure would also have been preferred over TTA by respondents in the present study. Surprisingly, however, only 1.6% of respondents selected the TR procedure as their preferred CCL repair method, whereas 13.9% favored TTA. In addition, the TR procedure was perceived by 43.3% of respondents as having the highest incidence of major complications. This perception was associated with surgeon training, with board-certified veterinary surgeons more often identifying this method as of highest risk than general practitioners and veterinarians limited to the practice of surgery who were residency trained but not board certified. Furthermore, the use of braided suture material, as used in a TR procedure, was perceived as providing the highest incidence of major complications by 86.1% of respondents. The main reasons cited for not using the TR procedure were infections and overall complications.

Our findings were similar to those of a previous study,<sup>4</sup> in which only 2% of surveyed ACVS diplomates and primary care veterinarians listed the TR procedure as their preferred method for their own dog. Interestingly, such adverse perceptions of the TR procedure in that study as well as in our survey contrast with reported findings of previous clinical studies,<sup>7,8,c</sup> which have indicated good to excellent outcomes when dogs with CCL-deficient stifle joints are treated with the TR procedure. In those studies,<sup>7,8,c</sup> an excellent outcome was achieved for 93% to 94% of treated dogs, and low major complication rates (13%) and low infection rates (2%) were reported following TR procedures. In addition, the data sheet provided by the manufacturer of the TR implant indicates a 94.9% success rate for the related surgery.<sup>70</sup> Surgeon bias<sup>17</sup> may be an explanation for the conflicting results of the present study and contrasting previous findings.<sup>7,26,70,c</sup> Indeed, the contrasting clinical studies and manufacturer data sheet indicating good to excellent outcomes were all authored or coauthored by the same group of investigators. Yet another explanation may be that the respondents in

the present study had limited experience with the TR procedure and thus greater technical difficulty performing this procedure than those with more experience, as previously described.<sup>71</sup>

The TR procedure is used in human orthopedics, but information on outcome is conflicting.<sup>72-85</sup> Indeed, although low complication rates (6% to 8%) and very good outcomes (97%) have been identified for people with various orthopedic conditions treated by TR in some studies,<sup>72-75</sup> contrarily, routine removal of the TR from the surgical site has been recommended<sup>76</sup> for people because of high complication rates ranging from 25% to 44%, including infection and implant loosening.<sup>76-85</sup>

Although 42.8% of respondents in the present study cited overall complications, including unsatisfactory short-term (28.9%) and long-term (38.0%) outcomes, as reasons for not using the TR procedure, the list of specific complications provided in the survey was limited. However, in addition to infection, 1 potential complication following TR surgery would be long-term loss of joint stability.<sup>m</sup> Indeed, implant failure was cited as a reason for not using the TR procedure by 29.9% of respondents. Implant failure in this instance could be caused by the greater strength and stiffness and lesser extensibility<sup>86</sup> of the TR implant, compared with biological tissue or other implants such as monofilament nylon, often used with the LFS method of CCL repair. Compared with other braided surgical implants, the greater abrasiveness of the TR implant while gliding through the eyelet of metal suture anchors has also been identified as a factor that could lead to implant loosening.<sup>87</sup> Similarly, abrasive soft tissue and bone injuries from the braided material used in the TR procedure have been associated with implant loosening after repair of rotator cuff tears in humans.<sup>88,89</sup> This destructive phenomenon has been referred to as a so-called cheese-wiring effect.<sup>88,89</sup>

With extracapsular techniques, suture anchorage at isometric points in the stifle joint has been recommended, despite the fact that the exact location of these specific points remains speculative at best and is likely to change throughout range of motion of the joint.<sup>90-95</sup> As a result, the general presumption is that sutures are subject to various tensile forces during the gait cycle.<sup>93</sup> Accordingly, one could speculate that, over time, stiff and abrasive suture materials such as braided multifilament suture may overcome the strength of bone or soft tissues used to anchor the material. In turn, this could lead to progressive widening of bone tunnels in which the material has been inserted and therefore to loss of joint stability. This explanation is supported by clinical observation of bone tunnel widening, not only when the TR procedure is used to stabilize CCL-deficient stifle joints, but also when used in other joints such as the shoulder joint when treating medial shoulder instability.<sup>m</sup> Interestingly, painful aseptic osteolysis surrounding braided multifilament suture and widening of bone tunnels with secondary loss of repair stability are also reported complications with the use of this material in humans.<sup>76,79-85</sup>

Although the perceived incidence of infection was cited by many (57.2%) respondents in the present study as a reason for not using the TR procedure, braided multifilament suture material (as used with the TR procedure) was perceived by even more respondents (86.1%) as resulting in a high incidence of major complications. The braided structure of the TR material and its potential effect on infection rate has been discussed.<sup>82,96</sup> Particularly, the braided, ultrahigh-molecular-weight polyethylene material of the TR implant has been shown to promote significantly higher bacterial adherence than achieved with monofilament nylon, polyethylene, and other braided materials.<sup>97,98</sup> This could explain the high prevalence of concerns about infection with the TR procedure as stated in the literature<sup>82,96</sup> and expressed by respondents in the present study.

Interestingly, the association between high infection rates and use of braided sutures to treat CCLR has long been recognized. Some studies<sup>99,100</sup> have revealed postoperative infection rates of up to 21%, and these infections were suggested to impair clinical function of the operated limb. Other studies<sup>101,102</sup> showed an incidence of postoperative infection of up to 50% when braided suture material was used. Although meticulous aseptic technique and adherence to additional preventative measures (eg, double gloving) have been recommended to decrease the incidence of infection, such recommendations may be even more important during TR procedures given that the risk of glove perforation has been noted to increase when handling the TR implant material.<sup>103</sup>

The perceived concerns associated with the CCL repair methods discussed here have also been noted by other researchers, resulting in changes in implant design and material. One example is a combination of TPLO with the TR procedure<sup>n</sup> to address reported stifle joint instability of unclear clinical importance following TPLO.<sup>104</sup> Given the results of our survey and previously reported concerns with braided suture material, caution may be warranted with such combinations. Another example is the development of TPLO plates made of titanium.<sup>9-9</sup> Given the aforementioned concerns regarding implant material and associated perception of risk for infection, it would be interesting to prospectively collect clinical information on such plates, as they combine the 2 factors (TPLO and titanium implants) most commonly perceived as having the lowest incidence of major complications in our study.

Although the present study was based on a survey and not a randomized controlled clinical trial, which represents a limitation, the demographics of the respondents suggested they were an experienced body of surgeons and veterinarians, and we therefore believe their impressions are not without merit. Another limitation of the study reported here was the inclusion of only VOS members. A larger study including a greater number of ECVS diplomates and general veterinary practitioners might have resulted in dif-



ferent results. For example, the TTA method was developed in Europe, where initial clinical data were collected,<sup>4,j</sup> and it is the authors' impression that, historically, TTA is more readily performed in Europe than in the United States. Similarly, our knowledge of and experience in teaching orthopedic procedures suggest that the LFS procedure is commonly taught to veterinary students and general veterinary practitioners, and therefore, general practitioners may perform this technique more frequently than any of the other evaluated methods. Consequently, if the number of general practitioners surveyed had been higher, the results may have been different.

Our response rate of 38.4% was similar to that in previous studies<sup>4,19,23,24</sup> and was higher than the 20% often anticipated for such surveys.<sup>105</sup> Importantly, because the VOS database does not differentiate between small or large animal practitioners, it was not possible to send the survey to small animal practitioners only. Consequently, the true response rate of small animal surgeons was unknown but was likely higher than reported. No validation of survey questions was performed, but this was similar to previous surveys.<sup>4,19,23,24</sup> During the study design, multiple statisticians were consulted, including an inquiry with participants of the National Conference for the American Statistical Association in 2016 to help with questionnaire validation. These specialists and a standard textbook<sup>106</sup> suggested that question validation was not indicated for the purpose of our study. Instead, pilot testing was recommended and performed.

Although method selection for CCLR treatment has often been based on surgeon preference,<sup>19</sup> likely because comparative studies and evaluation of long-term outcomes are lacking,<sup>107</sup> reasonable clinical evidence exists that TPLO provides better long-term outcomes than TTA and the LFS procedure<sup>9,33–36,52,58</sup> and is associated with a low complication rate.<sup>34–37,58</sup> The results of our survey supported these observations. Although a randomized controlled clinical trial would be necessary to validate the perceptions of our respondents, such studies are difficult to organize, particularly given that they should be conducted by independent investigators to reduce potential bias.<sup>108</sup> Until such data are available, we believe that the perceptions of the majority of respondents to our survey, who collectively performed nearly 30,000 CCLR surgeries annually, and the currently available literature suggest that TPLO should be reliably recommended for the surgical treatment of CCLR in dogs weighing > 15 kg.

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## Footnotes

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