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Correlation between the tibial plateau angle and occurrence of medial meniscal tears in dogs with complete cranial cruciate ligament rupture

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Abstract

Objective To determine whether there is a correlation between the degree of the tibial plateau angle (TPA) and the incidence of medial meniscal tear (MMT) in dogs with complete cranial cruciate ligament (CCL) rupture observed at the time of arthrotomy.

Methods 144 dogs met the inclusion criteria for this study with 88 (61.11%) found to have a MMT. Breed, age, sex, weight, affected limb, duration of lameness, and the integrity of contralateral stifle were recorded. Six groups were established based on TPA ranges measured in degrees.

Results There was a one-fourth reduction in the number of MMT observed in dogs with a TPA between 35 to 37 degrees and an almost two-fold reduction in the number of MMT in dogs with a TPA greater than 38 degrees. There was a 6 times greater risk of MMT in those with acute lameness in comparison to those with a chronic lameness.

Conclusion A relationship was found to exist between MMT and TPA with a lower prevalence of MMT in dogs with an excessive TPA. Chronic lameness was also associated with a lower prevalence of MMT regardless of TPA degree. In dogs with complete CCL tears, excessive TPA and chronic lameness were found to be statistically significant in relation to fewer MMT.

Keywords Stifle, Cruciate, Tibia, Plateau, Angle, Meniscus, Canine

Introduction

The menisci are crescent-shaped fibrocartilages that sit paired within the stifle joint on the medial and lateral surface of the tibia [1].They function in weight bearing, shock absorption, joint stability, and lubrication to protect the joint cartilage [1–3]. Their wedge shape enhances congruity between the femoral condyles and tibial plateau, increasing the area of load distribution and decreasing the area of direct femorotibial contact. Load-transmitting ability transforms compressive force into hoop stress, allowing distribution across a larger surface area to reduce damage to the articular cartilage [4, 5]. There are five meniscal ligaments attaching the meniscal fibrocartilage to the tibia but the medial meniscus also has attachments to the joint capsule and medial collateral ligament, increasing susceptibility to injury compared to the lateral meniscus [3, 4, 9].

In dogs, meniscal injury is almost always associated with complete or partial cranial cruciate ligament (CCL) rupture [4]. The main stabilizing structure of the canine stifle joint is the CCL [6], which prevents cranial tibial translocation relative to the femur, internal rotation, and hyperextension [3]. A strong relationship exists between medial meniscal tear (MMT) and CCL tear [7, 8] with a

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12.9 times increase in MMT identified in those with complete CCL tear compared to a partial tear [8]. The incidence of meniscal damage identified at the time of CCL rupture is reported as high as 77% [9]. Approximately 57% of meniscal tears are bucket-handle tears [7, 10], or vertical longitudinal tears [2]. Due to lack of adequate blood supply to the meniscus, with only 25% of peripheral blood flow and reduced regenerative ability, meniscectomy of the affected portion is the treatment of choice for meniscal injuries [3, 4, 6]. Partial meniscectomy is associated with fewer degenerative changes compared to total meniscectomy, still osteoarthritis development is inevitable [4].

Factors associated with increased risk of MMT include increased bodyweight [8, 11], severe osteoarthritis [9, 11, 12], joint effusion [11], age [9], complete CCL tears [7, 8], duration of lameness [8], male dogs [13], and certain breeds [8]. Conversely, a greater incidence of MMT was not found to be associated with weight, sex, side of injury, or lameness period before surgery [7, 12]. Multiple predisposing variables have been studied in relation to CCL rupture, with an excessive tibial plateau angle (TPA) being a controversial contributing factor [13–16]. No studies have correlated TPA and meniscal injury with complete CCL tears alone. Previous studies examined that a higher TPA increases cranial tibial thrust, putting additional stress on the CCL and thus increasing the risk of CCL rupture [3, 13, 14].

A retrospective study by Guastella et al. studied the TPA of 4 large breed dogs revealing no correlation between a higher TPA and an increased likelihood of meniscal tears [19]; however, a limitation of the study was that it did not differentiate between complete and partial CCL tears, and focused only on a subset of large breed dogs. The current study aims to expand on the previous data and determine whether a relationship exists between TPA and MMT in dogs with complete CCL tear. The hypothesis is that a correlation exists between TPA and prevalence of MMT at the time of arthrotomy in the presence of a complete CCL tear.

Methods

Medical records of client-owned dogs requiring stifle radiographs for TPA assessment were retrospectively reviewed from January 2023 to October 2023 between four hospitals to include seven ACVS board certified surgeons. Statistical analysis was performed using Microsoft® Excel® for Mac, version 16.84 and MedCalc Software. TPA categorized by degree range as follows: less than or equal to 25, 26–28, 29–31, 32–34, 35–37, greater than or equal to 38 degrees.

Criteria for case selection

The inclusion criteria for case selection were determined by: i) dogs diagnosed with a naturally occurring CCL at initial examination based on some degree of CCL instability confirmed by the presence of cranial tibial drawer/thrust; ii) stifle surgery including arthrotomy performed by an ACVS board certified surgeon; iii) complete CCL tear grossly observed intra-operatively; iv) integrity of the medial meniscus determined via arthrotomy; v) a recorded measurement of the traditional TPA performed by an ACVS board certified surgeon *or* appropriate variables including the degree of rotation and blade size to reference for the TPA; vi) no concurrent patella luxation or collateral ligament instability; vii) contralateral limb had no history of previous stifle injury or surgery, was stable on palpation (negative cranial drawer and tibial thrust), and if obtained, no radiographic evidence of stifle effusion recorded in the medical record.

Data collection

The collected data included breed, age, sex, weight, affected limb, duration of lameness, and the integrity of contralateral stifle. Surgery reports were evaluated for pre-operative TPA measurement or blade size used with degree of rotation in millimeters, approach to the joint, CCL tear and extent of the tear, presence and type of MMT, and appearance of the caudal cruciate ligament and lateral meniscus. All surgeons obtained TPA using components of a digital imaging tool on either Smart-PACS, eFilm, or Veterinary Preoperative Orthopedic Planning (vPOP) software in comparison to the Veterinary Orthopedic Implant (VOI) Rotation Chart [20]. The techniques consisted of stating TPA from two intersecting lines for tibial long axis and the tibial plateau [3, 21] or stating blade size and degree of rotation in millimeters used.

All surgeons performed a medial mini or full arthrotomy to observe pertinent stifle structures. The CCL was classified as a "partial" or "complete" tear. The medial meniscus was assessed using a stifle thruster or retractor for anterior tibia translation and meniscal probe in all cases. If MMT present, removal of the affected portion was performed. All operated limbs were reported to have a grossly normal and intact caudal cruciate and lateral meniscus. The presence of osteoarthritic changes and joint effusion relative to the stifle was not consistently recorded and therefore not considered in this study.

Results

During the 9-month study period, 360 dogs presented for evaluation of CCL tear and underwent surgery. Of those dogs, 216 were excluded due to: bilateral CCL tear,

Table 1 Data analysis of individual tibial plateau angle categories

TPA (degrees)	23-23.9	24-24.9	25-25.9	26-26.9	27-27.9	28-28.9	29-29.9	30-29.9	31-31.9	32-31.9	33-33.9	34-34.9	35-35.9	36-36.9	37-37.9	38-38.9	39-39.9	40+
# of cases per TPA	3	1	3	5	5	11	21	28	11	13	9	13	7	5	1	3	3	2
# of cases per group	7			21			60			35			13			8		
# of MMT	5			15			38			22			6			2		
Mean ± SD (degrees)	24 ± 1			27.31 ± 0.81			29.84 ± 0.72			33 ± 0.87			35.65 ± 0.72			39.56 ± 2.32		

TPA Tibial plateau angle (degrees), *MMT* Medial meniscal tear, *SD* Standard deviation

previous stifle stabilization on the contralateral limb, partial CCL tear observed by arthrotomy, concurrent medial patella luxation (MPL), medial collateral injury secondary to vehicular trauma, or undocumented variables needed for this study. Two dogs had a history of contralateral limb issues, tibial fracture, or femoral head and neck osteotomy and were not excluded from this study because the stifle joint was reportedly not affected during evaluation. A total of 144 dogs met the inclusion criteria and were included in this study.

Signalment

The included dogs comprised of 86 females, 5 intact and 58 males, 2 intact with ages ranging from 1 year 7 months to 13 years 4 months and weight ranging from 5.3 to 88.9 kg (kg). The Table 1 shows total number of dogs per group and the number of patients for each degree of TPA and corresponding MMT. The population mean TPA of the sample was 31 degrees, with 11 cases falling within the range of the entire population and 7 MMT of that group (63.64%). The group with the largest sample size and greatest number of dogs with meniscal injury were those with a TPA between 29–31 degrees. Fifty-six dogs had a TPA greater than the population mean of 31 degrees and 30 of those dogs had a MMT (53.57%). Of those, 21 dogs had an excessive TPA being greater than 35 degrees and 8 of those had a MMT (38.1%). A priori power analysis using G*Power Software version 3.1.9.6 was conducted to test ANOVA: fixed effects, omnibus, one-way for a sample size power calculation. The results indicated that evaluation of 7 dogs per each of the six TPA groups would be sufficient to correlate MMT to TPA with 80% power and 95% confidence ($\alpha = 0.05$).

Frequency data summary based on sex, age, neuter status, size by weight in kilograms, affected side, breed classification, and integrity of the MMT is presented in Table 2 by TPA categorization. Males 58 (40.28%), altered and intact with 36 MMT (62.07%) and females 86 (59.72%), intact or altered with 50 MMT (58.14%). Small breed dogs 9 (6.25%) with 4 MMT (44.44%), medium size 81 (56.25%) with 50 MMT (61.73%), and large size 54 (37.5%) with 34 MMT (40.96%). The affected limb included the right stifle 61 (42.35%) with 35 MMT (57.38%) and left stifle 83 (57.64%) with 53 MMT (63.86%). 54 dog breeds were categorized into groups; sporting 43 (29.86%) with 26 MMT (60.47%), hound 8 (5.56%) with 6 MMT (75%), working 14 (9.72%) with 7 MMT (50%), terrier 14 (9.72%) with 10MMT (71.43%), toy 6 (4.17%) with 3 MMT (50%), non-sporting 5 (3.47%) with 4 MMT (80%), herding 18 (12.5%) with 11 MMT(61.11%), mixed 22 (15.28%) with 13 MMT (59.1%), and other breeds not recognized by American Kennel Club classification 14 (9.72%) with 8 MMT (57.14%). Age was divided into 1 through 5 years old 46 (31.94%) with 25 MMT (54.35%), 6 through 9 years old 63 (43.75%) with 40 MMT (63.49%), and older than 10 years old 35 (24.31%) with 23 MMT (65.71%). Acute lameness less than 30 days 70 (48.61%) with 45 MMT (64.29%), subacute 31–150 days 48 (33.33%) with 26 MMT (54.17%), chronic lameness being longer than 150 days 11 (7.64%) with 3 MMT (27.27%), and unspecified 15 (10.42%) with 14 MMT (93.33%).

In conjunction with Table 1, TPA categorization relative to the number of dogs per grouping and MMT present is detailed in Fig. 1. TPA less than or equal to 25 degrees, 71.43% (MMT 5 of 7 dogs) and TPA of 26 through 28 degrees, 71.43% (MMT 15 of 21 dogs) were equivocal with the highest number of MMT. A slight reduction in MMT as TPA moved closer to the mean with a TPA of 29 through 31 degrees, 63.33% (MMT 38 of 60 dogs) and TPA of 32 through 34 degrees, 37.14% (MMT 22 of 35 dogs). A significant decrease in the number of MMT was found as the TPS became more excessive from 35 through 37 degrees, 53.85% (MMT 6 of 13 dogs), and 38 degrees or higher, 25% (MMT 2 of 8 dogs).

Individual factors described in Table 2 were further analyzed for an association with MMT and are presented in Table 3 based on Odds Ratio (OR), 95% Confidence Interval (CI), and p-value. Significance was set at p-value < 0.05. Increased bodyweight, sporting breed, and increased age were not statistically significant relative to fewer MMT. Excessive TPA and chronic lameness were

Table 2 Analysis of dogs with complete CCL tear requiring TPA measurement and meniscus evaluation

			TPA																							
	Total		≤ 25°				26–28°				29–31°				32–34°				35–37°				≥38°			
	Frequency		Frequency		Medial Meniscus		Frequency		Medial Meniscus		Frequency		Medial Meniscus		Frequency		Medial Meniscus		Frequency		Medial Meniscus		Frequency		Medial Meniscus	
Variable	**(*n*)**	**(%)**	(*n*)	(%)	Torn	Intact	(*n*)	(%)	Torn	Intact	(*n*)	(%)	Torn	Intact	(*n*)	(%)	Torn	Intact	(*n*)	(%)	Torn	Intact	(*n*)	(%)	Torn	Intact
Sex																										
Altered																										
Male	**56**	**38.89**	0	0.00	0	0	6	4.17	5	1	30	20.83	18	12	11	7.64	9	2	6	4.17	4	2	2	1.39	0	2
Female	**81**	**56.25**	6	4.17	4	2	12	8.33	7	5	26	18.06	17	9	24	16.67	13	11	7	4.86	3	4	6	4.17	2	4
Intact																										
Male	**2**	**1.39**	1	0.69	1	0	1	0.69	1	0	1	0.69	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Female	**5**	**3.47**	0	0.00	0	0	2	1.39	2	0	3	2.08	2	1	0	0	0	0	0	0	0	0	0	0	0	0
Size by weight																										
Small (<10kg)	**9**	**6.25**	0	0.00	0	0	1	0.69	0	1	1	0.69	0	1	4	2.78	2	2	2	1.39	1	1	1	0.69	1	0
Medium (10-30kg)	**81**	**56.25**	5	3.47	3	2	6	4.17	4	2	34	23.61	22	12	22	15.28	15	7	9	6.25	5	4	5	3.47	1	4
Large (>31kg)	**54**	**37.50**	2	1.39	2	0	14	9.72	11	3	25	17.36	16	9	9	6.25	5	4	2	1.39	0	2	2	1.39	0	2
Side																										
Right	**61**	**42.36**	5	3.47	3	2	7	4.86	5	2	26	18.06	17	9	13	9.03	7	6	5	3.47	1	4	5	3.47	2	3
Left	**83**	**57.64**	2	1.39	2	0	14	9.72	10	4	34	23.61	21	13	22	15.28	15	7	8	5.56	5	3	3	2.08	0	3
Breeds																										
Sporting	**43**	**29.86**	1	0.69	1	0	6	4.17	4	2	18	12.50	13	5	12	8.33	7	5	3	2.08	1	2	3	2.08	0	3
Hound	**8**	**5.56**	1	0.69	0	1	0	0.00	0	0	2	1.39	1	1	3	2.08	3	0	1	0.69	1	0	1	0.69	1	0
Working	**14**	**9.72**	0	0.00	0	0	2	1.39	2	0	3	2.08	0	3	4	2.78	3	1	3	2.08	2	1	2	1.39	0	2
Terrier	**14**	**9.72**	0	0.00	0	0	1	0.69	1	0	7	4.86	5	2	4	2.78	3	1	1	0.69	0	1	1	0.69	1	0
Toy	**6**	**4.17**	0	0.00	0	0	1	0.69	0	1	2	1.39	1	1	1	0.69	1	0	2	1.39	1	1	0	0.00	0	0
Non-sporting	**5**	**3.47**	1	0.69	1	0	1	0.69	0	1	2	1.39	2	0	1	0.69	1	0	0	0.00	0	0	0	0.00	0	0
Herding	**18**	**12.50**	2	1.39	1	1	4	2.78	3	1	10	6.94	5	5	2	1.39	2	0	0	0.00	0	0	0	0.00	0	0
Mixed	**22**	**15.28**	2	1.39	2	0	3	2.08	3	0	9	6.25	6	3	6	4.17	1	5	2	1.39	1	1	0	0.00	0	0
Other	**14**	**9.72**	0	0.00	0	0	3	2.08	2	1	7	4.86	5	2	2	1.39	1	1	1	0.69	0	1	1	0.69	0	1
Age (years)																										
1-5	**46**	**31.94**	2	1.39	2	0	8	5.56	6	2	20	13.89	9	11	11	7.64	6	5	3	2.08	1	2	2	1.39	1	1
6-9	**63**	**43.75**	2	1.39	2	0	8	5.56	5	3	30	20.83	21	9	13	9.03	10	3	5	3.47	2	3	5	3.47	0	5
10+	**35**	**24.31**	3	2.08	1	2	5	3.47	4	1	10	6.94	8	2	11	7.64	6	5	5	3.47	3	2	1	0.69	1	0
Lameness period (days)																										
Acute (<30)	**70**	**48.61**	5	3.47	4	1	14	9.72	8	6	28	19.44	18	10	15	10.42	11	4	4	2.78	2	2	4	2.78	2	2
Subacute (31-150)	**48**	**33.33**	1	0.69	0	1	5	3.47	3	2	21	14.58	14	7	12	8.33	6	6	6	4.17	3	3	3	2.08	0	3
Chronic (>150)	**11**	**7.64**	0	0.00	0	0	0	0.00	0	0	3	2.08	1	2	4	2.78	1	3	3	2.08	1	2	1	0.69	0	1
Unspecified	**15**	**10.42**	1	0.70	1	0	2	1.39	2	0	8	5.56	1	0	4	2.78	2	0	0	0.00	5	3	0	0.00	3	1

Percent (%) of the number (n) of cases per TPA category

TPA Tibial plateau angle, *Kg* Kilograms

found to be statistically significant in relation to fewer MMT.

Meniscal pathology

A classification of MTT for a total of 88 dogs (61.11%) is explained in Table 4. Type II MMT 55 dogs (62.5%), type II MMT 4 dogs (4.55%), type III MMT 26 dogs (29.55%), and in 3 dogs the MMT was unspecified (3.4%). There was found to be an even distribution of each MMT type between all TPA ranges.

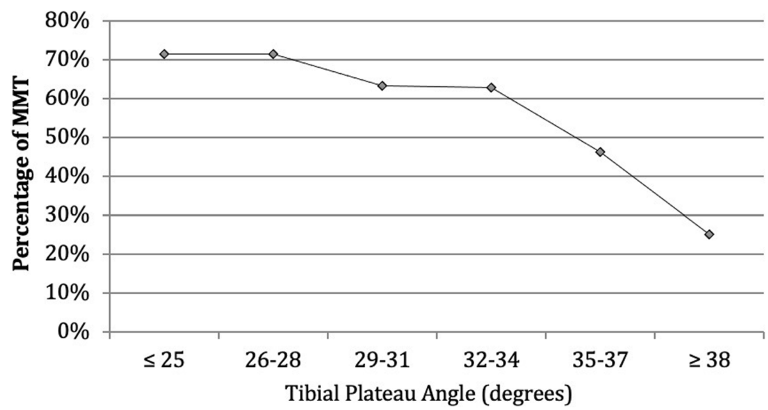

Fig. 1 Correlation exists between excessive TPA and reduction of medial meniscal tears within groupings of dogs with a complete cranial cruciate ligament rupture

Table 3 Analysis of risk factors associated with a lower prevalence of MMT

Risk Factor	Odds Ratio	95% Confidence Interval	z statistic	p-value
Excessive TPA	0.3308	0.1272 to 0.8600	2.269	0.019
Increased bodyweight	1.1333	0.5657 to 2.2707	0.353	0.726
Sporting breed	0.962	0.4632 to 1.9981	0.104	0.918
Increased age	1.2974	0.5853 to 2.8759	0.641	0.524
Chronic lameness	0.1985	0.0502 to 0.7854	2.304	0.017

Table 4 Reference system for the classification of dogs with MMT at the time of arthrotomy

Type	Description	Example
I	Appropriately attached at both horns, single body tear with/without displacement	Bucket handle/vertical longitudinal, superficial, transverse/horizontal
II	Appropriately attached at both horns, multiple body tears with/without displacement	Radial, serial bucket handle
III	Complete detachment of a single horn with/without concurrent tear present	Caudal/peripheral detachment

Discussion

Complete CCL rupture has previously been associated with 12.9 times increased risk of meniscal injury [8], therefore all partial CCL ruptures were omitted from the present study for consistency. Reasoning behind this association between complete CCL and MMT is the shear force on the caudal aspect of the stifle joint when the tibia moves cranially relative to the femur [6]. An excessive TPA, defined as 35 degrees or greater [16], was not found to correlate with an increased number of MMT. There was found to be a one-fourth reduction in the number of MMT observed in dogs with a TPA between 35 to 37 degrees and an almost two-fold reduction in the number of MMT in dogs with a TPA greater than 38 degrees.

A potential explanation for the decreased likelihood of MMTs in patients with an excessive TPA greater than 35 degrees may be attributed to lameness which was the only other factor besides excessive TPA proven to be statistically significant. A previous study found the risk of a MMT increased by approximately 2.6% for each week of lameness [8], however discredited in the current study. Fewer MMT were found with chronic lameness; however, a small number of cases existed in this category in comparison to acute and subacute lameness. There was a 6 times greater risk of MMT in those with acute lameness in comparison to those with a chronic lameness. A theory for this conclusion is that dogs with an excessive TPA may have more prominent lameness once complete CCL rupture occurs and thus may seek surgical evaluation earlier. As the compressive load increases within the stifle joint, the tensile forces exerted on the collateral ligament are unchanged [22]. Although an excessive TPA increases the stress of the CCL, there may be a possibility that be no additional stress is placed on the medial collateral ligament and strain on the closely associated medial meniscus with a steeper TPA.

Those with the highest number of MMT included male dogs, intact and altered, medium size dogs between 10 to 30 kg, non-sporting breed, younger age between 1 through 5 years old, and those with acute lameness less than 30 days duration. The breeds within the non-sporting group within this study include the Poodle, Bulldog, and Bichon Frishe. This finding differs from a previous report finding of an increased risk of MMT found within Retrievers and Rottweilers [8] which are classified within the sporting and working breed, respectively. Type I MMT were overrepresented, supporting previous studies [2, 7, 10]. An increased body weight was not found to be a contributing factor to MMT; however, this study does not account for body condition score relative to the individual patient which may falsely affect the size of the animal.

In conclusion, a relationship was found to exist between MMT and TPA with a lower prevalence of MMT in dogs with an excessive TPA. Chronic lameness was also associated with a lower prevalence of MMT regardless of TPA degree. As the TPA becomes excessive in the presence of a CCL tear, there is a reduced likelihood of medial meniscal pathology, ultimately reducing the need for meniscectomy and potentially lowering progression of osteoarthritis after stifle stabilization.

Potential for future research exists and should investigate why there is a lower risk of meniscal tears with increasing TPA and utilize a larger sample population, use of arthroscopy with meniscal probe, and consider bilateral CCL disease or previous stifle stabilization. Another consideration for future research that may correlate with duration of lameness would be to evaluate the degree of muscle atrophy which involves shifting the active and passive forces within the stifle [6], and effect on the shearing force on the caudal aspect of stifle joint and caudal horn of the medial meniscus.

Limitations

Several limitations exist and are related to limited sample size of those with an excessive TPA. Almost two-thirds of the evaluated cases did not meet the inclusion criteria in an attempt to narrow additional factors that may affect the stifle joint. The TPA was obtained by different methods, and also variations in measuring the tibial plateau slope may occur from patient positioning during the limb radiograph and observer error during this measurement [23]. Inter- and intra-observer variability is inevitable but was found to be small, 0.8 degrees and 1.5 degrees, respectively [23]. To reduce observer variability, all surgeons used a planning program which simplifies the calculation of TPA and reduces the possibility of observer error [24].

With the retrospective nature of the current study, some information within the medical records might have been incomplete such as consistent distinction between competent versus incompetent remnants of a partial CCL tear, contralateral stifle radiographs ruling out signs of early CCL tear, and a single user not obtaining TPA measurement. The classification system for MMT was not present at the time of surgery and may not be described appropriately within the surgery report. Arthroscopy and meniscal probing have been shown to be 9 times more successful at detecting meniscal pathology [2] and is the gold standard [3, 9, 17, 18]. A significant limitation is that arthroscopy was not used, however meniscal probes were used in all cases which has been reported to increase the odds of a correct diagnosis of MMT by 2–3 times at the time of athrotomy [2].

Abbreviations

CCL	Cranial cruciate ligament
MMT	Medial meniscal tear
TPA	Tibial plateau angle
MPL	Medial patella luxation
OR	Odds ratio
CI	Confidence interval

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JB collected, analyzed and organized the data and wrote the manuscript; GA editor; DM editor.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
No permissions were necessary to collect the data in this study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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