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IN VITRO MECHANICAL TESTING OF MONOFILAMENT NYLON FISHING LINE, FOR THE EXTRACAPSULAR STABILISATION OF CANINE STIFLE JOINT

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Abstract

Cranial cruciate ligament (CCL) rupture is a common injury in the dogs and major cause of degenerative joint disease. A common method to restore stifle joint stability is an extra capsular repair with a lateral fabella-tibial suture using heavy nylon wire. Aims: to compare the mechanical properties (force at failure and elongation) of three diameters of nylon fishing line before and after steam sterilizer with loops secured by knot (two types) and by crimped system. Materials and methods: Two monofilament nylon fishing lines (1 and 1.2 mm) were used to determine the effect of steam sterilization on strength and elongation of the material. A strand of each diameter of monofilament nylon fishing material was knotted or crimped to form a loop around 2 rods on a materials-testing machine. Material testing was performed using a servo-hydraulic materials-testing machine. Twenty trials of each diameter of unsterilized and steam-sterilized nylon per each type of secured methods were tested. A strand of each material was elongated to failure at a constant displacement of 10 mm/min to determine strength. A strand of each material was cycled 10 times to a load of 50 N to determine percent elongation. Results: All the loops failed by breaking or slipping within the knot or clamp. The surgeons knot had significantly greater elongation than all other loops, but required the most force to failure. With incremental loading, knotted loops elongated more than crimped loops. The loops secured by indigene crimp system were weaker strength than knotted loops.
Conclusion: All materials tested exceeded the necessary strength of neutralizing the load in the canine walk but none exceeded the estimated highest load during canine higher activity.

***Key words**: cranial cruciate ligament surgery, dog, lateral suture, monofilament nylon; surgery.*

INTRODUCTION

Cranial cruciate ligament (CCL) rupture is a common injury in the dog and a major cause of degenerative joint disease. The pathophysiology of CCL rupture in the dog is well described (Vasseur, 1993; Piermattei and Flo, 1997). Osteoarthritis secondary to CCL rupture causes severe pain and lameness (Piermattei and Flo, 1997). There are many surgical techniques accepted for dogs with CCL rupture (DeAngelis and Lau, 1970; Flo, 1975; Arnoczky et al., 1979; Hulse et al., 1980; Shires et al., 1984; Slocum and Devine, 1985; Smith and Torg, 1985; Slocum and Slocum, 1993; Vasseur, 1993; Piermattei and Flo, 1997; Montavon et al., 2002).
A commonly performed technique is an extracapsular repair with a lateral fabella-tibial suture (LFS) using large diameter nylon leader line (NLL), (Flo, 1975). The lateral fabella-tibial suture is used commonly because of its ease of application and good clinical outcome (Banwel, 2004).
The ideal suture material should be strong, aseptic, easily handled, inexpensive, and must provide excellent knot security and knot compactness. Numerous studies have determined nylon leader line to have the most appropriate characteristics for use as a lateral fabella-tibial suture (Thorson et al., 1989; Prostredny et al., 1991; Caporn and Roe, 1996; Lewis et al., 1997; Anderson et al., 1998; Nwadike and Roe, 1998; Huber et al., 1999; McKee and Miller, 1999; Sicard et al., 1999; Peycke et al., 2002; Sicard et al., 2002). Appropriate characteristics for use as a lateral fabella-tibial suture include a high force at

failure, a small amount of elongation, and high stiffness (Huber et al., 1999). However, because of the NLL memory, low coefficient of friction, and large diameter, knot security may still be a problem (Banwel, 2004).
Sicard et al. (2002) evaluated the mechanical properties of two brands of monofilament nylon fishing line and three brands of monofilament nylon leader line and concluded that all materials tested, Mason leader line and Sufix fishing line had the best mechanical properties for extracapsular stabilization of the canine stifle joint. Extracapsular stabilization using a LFS requires a strong suture material that minimizes bacterial adherence and has minimal plastic deformation (Nwadkie and Roe, 1998).
In this study we aim to compare the mechanical properties (force at failure and elongation) of two diameters of nylon fishing line available on the market in Romania, before and after steam sterilizer, with loops secured by knot and by commercial (fishing) crimped system. Two monofilament nylon fishing lines (1 and 1.2 mm) were used to determine the effect of steam sterilization on strength, stiffness, and elongation of the material.

MATERIALS AND METHODS

The materials tested were 1.0 and 1.2 mm monofilament nylon fishing line (NFL). Twenty trials of each diameter of unsterilized and steam-sterilized nylon per each type of secured methods: 1. - square knot, with a total three throw (SQ), 2. - surgical knot, with a total four throw (SK), and with 3. - a fishing commercially crimp-clamp (CC) were tested. A strand of each diameter of monofilament nylon fishing material was knotted or crimped to form a loop around 2 rods (a customized 40 mm outer diameter) on a materials-testing machine. The ends of all loops were cut 3 mm from the knot or clamp.
Material testing was performed using a servo-hydraulic materials-testing machine (MULTITEST 5-i) and analyzed by Emperor Force soft (Figure 1). Elongation, stiffness, and strength of each loop were tested.

For the non-cycled testing, tension was applied at a constant distraction rate of 10 mm/min until the loops failed by breaking or slipping.
A strand of each material was cycled 10 times to a load of 50 N to determine percent elongation.

Figure 1. The servo-hydraulic materials-testing machine (MULTITEST 5-i)

For both tests (non-cycled and cycled), calculations to determine force at failure, elongation, and stiffness were collected from the final load to failure cycle for each trial. Force at failure, elongation, and stiffness were recorded and compared across sizes of NFL, fixation method and unsterilized and steam-sterilized wires. The stiffness measurement reported was the maximum recorded value obtained from the linear portion of the load vs. elongation curve for each trial.

All data was summarized as mean +/- SEM. The force at failure and elongation were evaluated for normality using the t-Student test with the null hypothesis of normality rejected at $p<0.05$. The stiffness was analyzed by Emperor Force soft as a diagram.

RESULTS AND DISCUSSIONS

In the non-cycled testing all the loops failed at a portion originally contained within the knot or crimp-clamp. All loops secured by CC, cycled sample failed by slipping prior to completion of cycled protocol.

Results of the mechanical properties (force at failure and elongation) of two diameters of nylon fishing line (1 and 1.2 mm) available on the market in Romania, before and after steam sterilizer, with loops secured by knot (SQ and SK) and by commercial (fishing) crimped system are presented in the table below (Table 1).

The force at failure was significantly greater in all SK loops than in the SQ loops. The force at failure was significantly greater in steam sterilized loops than in non-sterilized loops.

Data presented in the next table (Table 2) shows a consistent, significant effect of sterilization method on the force at failure and elongation of the NFL for each tensile strength tested. All of the steam sterilized samples showed a strong significant increase of elongation, strength, and time of failure when compared to non-sterilized samples.

The load–deformation curve – the stiffness for loops secured by SQ, SK and CC (Figures 2, 3 and 4) shows important increase of ability to resist a tensile force prior to failure for NFL loops secured with SK.

Table 1. Mean ± S.E. force at failure, elongation, and time of failure for loops formed with square knot (SQ), surgical knot (SK), and fishing commercially crimp-clamp (CC) using two size of NFL unsterilized and steam-sterilized

Sample			Elongation (mm)	
Size mm	Sterilized status	Secured	50 (N)	F max(N)
1	steam-sterilized	SQ	3.97±0.27	11.42±0.84
		SK	3.78±0.14	23.90±1.87
		CC	2.78±0.97	7.01±3.45
	unsterilized	SQ	2.44±0.51	8.96±1.01
		SK	2.14±0.29	13.19±1.46
		CC	1.45±0.45	2.79±4.37
1.2	steam-sterilized	SQ	2.66±0.09	11.87±1.20
		SK	3.47±0.15	25.22±6.29
		CC	10.35±0.19	11.47±0.33
	unsterilized	SQ	1.70±0.03	10.24±0.15
		SK	2.27±0.43	16.42±2.53
		CC	10.37±0.19	11.47±0.33
			Force of failure (N)	Time of failure (sec.)
1	steam-sterilized	SQ	143.74±12.50	70.97±6.45
		SK	442.66±14.03	147.24±12.84
		CC	126.16±23.54	42.21±20.50
	unsterilized	SQ	173.01±13.81	54.57±5.96
		SK	378.13±34.36	76.15±12.32
		CC	39.84±14.35	21.63±22.90
1.2	steam-sterilized	SQ	249.31±47.98	71.28±7.64
		SK	537.99±137.05	151.16±38.03
		CC	88.3±3.98	68.73±1.43
	unsterilized	SQ	289.32±2.48	61.55±0.90
		SK	634.4±94.56	98.71±14.97
		CC	88.33±3.98	68.75±1.44

Table 2. p values (t-Student test) when compared: two size of NFL, unsterilized versus steam-sterilized, for force at failure and elongation - loops secured with square knot (SQ) and surgical knot (SK)

Sample compared			Elongation (mm)	
Size mm	Sterilized status	Knot	50 (N)	F max (N)
1	Unsterilized/steam-sterilized	SQ	2.63×10^{-10}	5.20×10^{-8}
	Unsterilized/steam-sterilized	SK	8.01×10^{-15}	1.18×10^{-15}
1.2	Unsterilized/steam-sterilized	SQ	4.88×10^{-21}	1.65×10^{-5}
	Unsterilized/steam-sterilized	SK	1.22×10^{-8}	0.0001
			Force of failure (N)	Time of failure (sec.)
1	Unsterilized/steam-sterilized	SQ	-	-
	Unsterilized/steam-sterilized	SK	1.97x 10-8	4.35×10^{-7}
1.2	Unsterilized/steam-sterilized	SQ	4.24×10^{-7}	1.71×10^{-12}
	Unsterilized/steam-sterilized	SK	0.0004	3.06×10^{-5}

The clinical importance of evaluating elongation of materials for LFS has been questioned by previous investigators (Huber et al., 1999). Ideally, a strong material with a high stiffness is desirable since it would allow minimal elongation when subjected to loads less than that of failure. With this consideration, FNL appears to be mechanically equivalent to NLL of the same tensile strength.

Evaluation of the load vs. elongation curves for each tensile strength and type of material tested revealed that the NFL underwent an interesting trend. The large diameters make it difficult to form a tight knot. This initial elongation could represent knot tightening under low load or could be a result of a material property of the NFL. Previous studies have demonstrated similar findings (Caporn and Roe, 1996).

Steam sterilization had profound effects on each tensile strength of NFL tested. A significant increase of elongation and force of failure was observed. These effects were proportional to the size of the material. These recorded data contrast with data obtained by Banwel (2004) who reports significant increases in elongation for fluorocarbon fiber after steam sterilization, as well as reduction of stiffness which make the mechanical properties of this wire unacceptable for use as a LFS.

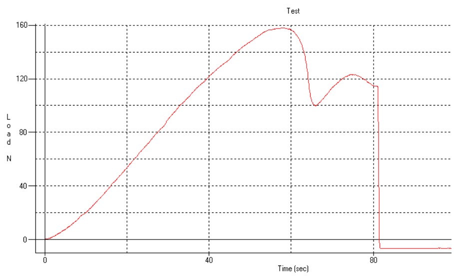

Figure 2. The load–deformation curve for loops secured by SQ

There has been a variety of studies looking at various knot formations and alternatives to knotting when using NLL (Anderson et al., 1998; Peycke et al., 2002). Although Huber et al. (1999), Vianna and Roe (2006), Peycke et al. (2002) and Roe et al. (2008) reported that clamping the first throw of a square knot was found to increase the structural stiffness of the loop, allowing the formation of a tighter, more secure knot, in our study data recorded reveal that commercial (fishing) crimped system tested are unacceptable for use as a LFS. Similar findings reports Burgess et al. (2010).

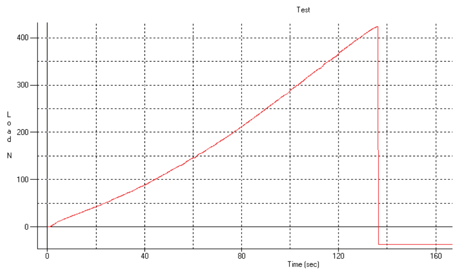

Figure 3. The load–deformation curve for loops secured by SK

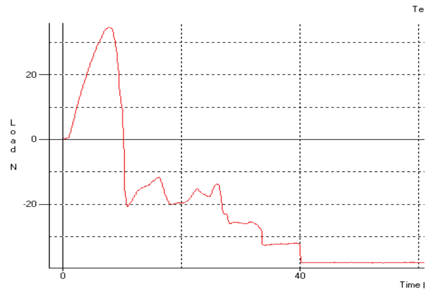

Figure 4. The load–deformation curve for loops secured by CC

Although in vivo physiologic forces of the canine cruciate ligament have not yet been defined (Rose et al., 2012), numerous studies (Caporn and Roe, 1996; Wingfield et al., 2000; Burgess et al., 2010) estimated that canine CCL resists to a load of 50 N at walk and up to 400–600 N during higher activity. The lowest estimated physiologic load (dogs between 30 and 60 kg) of the canine CCL is estimated to be 126 N (Rose et al., 2012). Results of our study reveal that NFL has the capacity of neutralizing the load in the canine walk but none exceeds the estimated highest load during canine higher activity.

CONCLUSION

For the two size of NFL tested, the surgeons knot had significantly greater elongation than all other loops, but required the most force to failure.

The NFL loops secured by indigene crimp system were weaker in strength than the knotted loops.

Steam sterilization of NFL produced a significant increase of elongation and force of failure.

The two size of NFL tested exceeded the necessary strength of neutralizing the load in the canine walk, but none exceeded the estimated highest load during canine higher activity.

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