Mechanical testing of orthopaedic suture material and a crimp clamp system for the extracapsular stabilisation of canine cruciate-deficient stifles

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ABSTRACT: The cranial cruciate ligament (CCL) provides cranio-caudal stability, prevents hyperextension and constrains medial rotation of the tibia in the canine stifle joint and CCL rupture is the leading cause of hind leg lameness in dogs. Treatment of CCL rupture aims to resolve lameness caused by joint instability and provide good long-term function of the affected hind limb. The extracapsular technique is one of the most popular methods to restore joint stability. The technique involves a suture loop that is placed around the lateral fabella and through the tibial tuberosity. The ideal suture material should be strong, aseptic, easily handled, inexpensive, and provide excellent knot security and knot compactness. A critical property of the loop is the application of either a knot or crimp to maintain the tension on the loop. There is a variety of orthopaedic suture materials used for the extra-capsular technique. Our aim was to compare the mechanical properties of four commercially available materials in pure tension. The materials tested were monofilament nylon leader (MNL) 100 lb, MNL 80 lb, Supramid and Silon. Our second objective was to compare the interoperator variability of applying either a knot or a crimp to secure the suture loop. Ultimate tensile strength was greatest with MNL 100 lb (373 N) followed by MNL 80 lb (285 N), Supramid (160 N) and Silon (103 N). Based on our results, we conclude that MNL 100 lb and MNL 80 lb are mechanically superior to Silon and Supramid. Our study also shows significant effects for the operator and method of loop fixation ($P < 0.0001$). Intraoperator differences were also found to be significant, for operator 1 ($P < 0.0001$), for operator 2 ($P < 0.001$) and operator 3 ($P < 0.01$). Our findings indicate that MNL is most suitable orthopaedic material and that loop fixation should remain the method of choice for surgeons treating CCL.

Keywords: dog; cranial cruciate ligament rupture; surgery; lateral suture; knee joint

The cranial cruciate ligament (CCL) provides cranio-caudal stability, prevents hyperextension and constrains medial rotation of the tibia in the canine stifle joint. CCL rupture is the leading cause of hind leg lameness; it is also the most frequent cause of degenerative disease of the canine stifle joint (Arnoczky and Marshall 1977; Johnson and Johnson 1993; Vasseur 2003; Piermattei et al. 2006; Boudrieau 2009). The cause of rupture is often unknown and the optimal method of therapy is still debated (Necas et al. 2000; Lampman et al.

2003). Treatment of CCL rupture aims to resolve lameness caused by joint instability and provide good long-term function of the affected hind limb. Over the last few decades a large number of surgical techniques have been reported for the treatment of this condition. However, to date, there is no procedure that demonstrates unambiguously superior clinical efficacy (Kim et al. 2008) and all surgical treatments only provide temporary stability. Meanwhile, periarticular fibrosis is responsible for the final stability of the stifle joint, irrespective

of the technique used. Extracapsular stabilisation with a lateral fabello-tibial suture is a commonly performed technique. This technique was first described by DeAngelis and Lau (1970) and was later modified by Flo (1975). The technique involves a suture loop that is placed around the lateral fabella and through the tibial tuberosity. A critical property of the loop is the application of either a knot or crimp to maintain the tension on the loop. According to Vianna and Roe (2006) crimped loops are stiffer and resist static and cyclic loads more effectively before becoming permanently elongated, when compared with knotted loops (Vianna and Roe 2006), although the decision to apply either a knot or a crimp is dependent on the preference of the surgeon. The material used should ideally be strength, aseptic, easily handled, inexpensive, and provide excellent knot security and knot compactness (Banwell et al. 2005). There is a variety of materials used for the suture, including a new generation of orthopaedic suture materials which include FiberWire, FiberTape and OrthoFiber. However, the most common material used by surgeons is monofilament nylon leader (MNL). Our aim was to compare the mechanical properties of four commercially available materials in pure tension. Our second objective was to compare the interoperator variability of applying either a knot or a crimp to secure the suture loop.

MATERIAL AND METHODS

Suture materials

The materials tested included: Silon braided EP7 USP5 (Chirmax, Prague, Czech Republic), Supramid PA 7 metric USP5 (Resorba, Nürnberg, Germany) and 100 lb and 80 lb MNL (Veterinary Instrumentation, Sheffield, United Kingdom). All materials were in sterile packaging when purchased.

Mechanical testing

Three samples of each suture were tested for load to failure. Material testing was performed using a servo-hydraulic materials-testing machine (TIRAtest 2300, VEB TIR NDR). The Certificate of Authentication number of the machine was 0305/323.04/11. The samples were divided into

Figure 1. Wrapped material construct on the servo-hydraulic material-testing machine

three groups. The first group contained three samples of all material wrapped around a 30 mm steel rod secured with a screw (Figure 1). The second group contained three constructs of loops of all material tied by D.K. with a surgeons knot and two additional throws, while the third group contained three loops of 80 lb and 100 lb MNL secured by D.K. with a crimp clamp. The steel rods were 100 mm apart for all samples.

Three experienced surgeons familiar with the crimping technique were chosen for the second part of the study. Each operator secured four loop samples of 80 lb MNL with a surgeon's knot and two additional throws and four loop samples of 80 lb MNL with a crimp. Three evenly spaced pinches were made into each crimp. These constructs were put on the same rods, 100 mm apart as described above.

Altogether, 54 samples underwent monotonic tensile loading at 300/min until failure. Only midbody suture breakage was accepted for data analysis. The location of the failure was recorded.

Statistical analysis

All data were entered into a spread sheet program (Microsoft Office Excel 2007, Microsoft Corporation) and imported into statistical software (GraphPad Prism 5, GraphPad Software, Incorporated) for analysis. Values were reported as the mean ± SD. Mechanical testing of four different materials were analysed using 1-way ANOVA. Interoperator differences were analysed using two-way ANOVA. Intraoperator differences were analysed using the *t*-test. Statistical significance was set at $P < 0.05$.

RESULTS

Ultimate tensile strength was greatest with MNL 100 lb (373 ± 38.1 N) followed by MNL 80 lb (285 ± 73.2 N), Supramid (160 ± 4.5 N) and Silon (103 ± 2.1 N) (Figure 2, Table 1). MNL 100 lb and MNL 80 lb, although not significantly different from each other, were significantly stronger than all other ma-

terials tested ($P < 0.0001$). Supramid and Silon were not significantly different from each other.

The majority of knotted samples failed at the knot. Only MNL 100 lb (288 ± 46.2 N) was significantly stronger than Silon (152 ± 4.0 N) ($P < 0.01$).

All loops secured by a crimp failed by slipping through the crimp tube. There was no significance difference between MNL 100 lb (349 ± 31.8 N) and MNL 80 lb (295 ± 132.4 N) ($P > 0.05$).

The ultimate load for knotted loops of 80 lb MNL for operators 1, 2 and 3 were 375 ± 48.0 N, 249 ± 42.5 N and 231 ± 59.5 N, respectively. The ultimate crimped loops of 80 lb MNL for operators 1, 2 and 3 were 103 ± 36.6 N, 359 ± 24.0 N and 325 ± 30.6 N, respectively (Figure 3, Table 2). The ANOVA demonstrated significant effects for operator and method of loop fixation ($P < 0.0001$). Intraoperator differences were also significant, for operator 1 ($P < 0.0001$), for operator 2 ($P < 0.001$) and operator 3 ($P < 0.01$). All but one of the knotted loops failed the knot, and all crimped loops failed by slipping through the crimp tube.

Table 1. Mean (± SD) load at failure

	Ultimate tensile strength (N)
Silon	103 ± 2.1
Supramid	160 ± 4.5
MNL 100 lb	373 ± 38.1
MNL 80 lb	285 ± 73.2

MNL = monofilament nylon leader

Table 2. Mean (± SD) load at failure for two different loop constructs made by three different operators

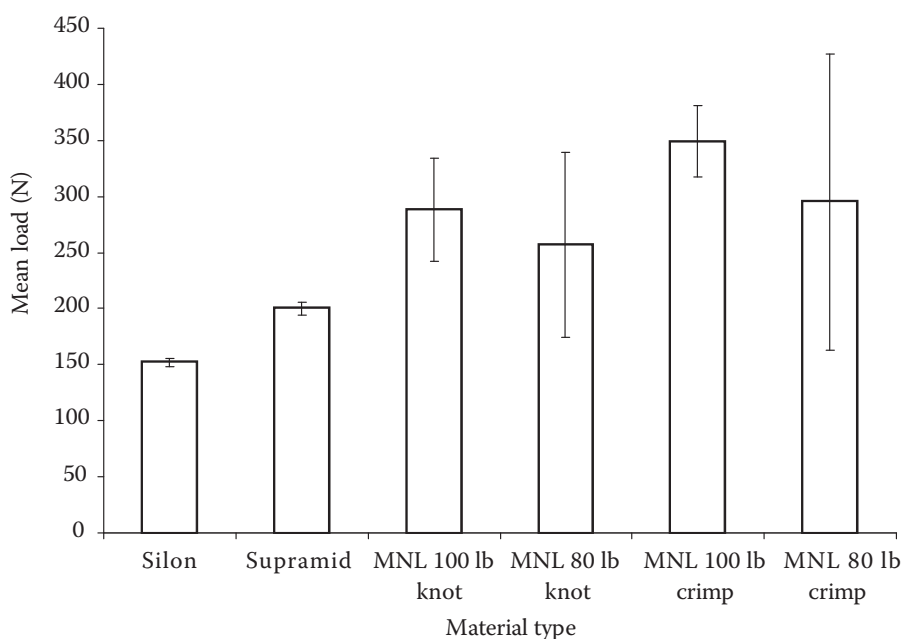|	Ultimate load at failure (N)	
	crimp	knot
Operator 1	103 ± 36.6	375 ± 48.0
Operator 2	359 ± 24.0	249 ± 42.5
Operator 3	325 ± 30.6	231 ± 59.5

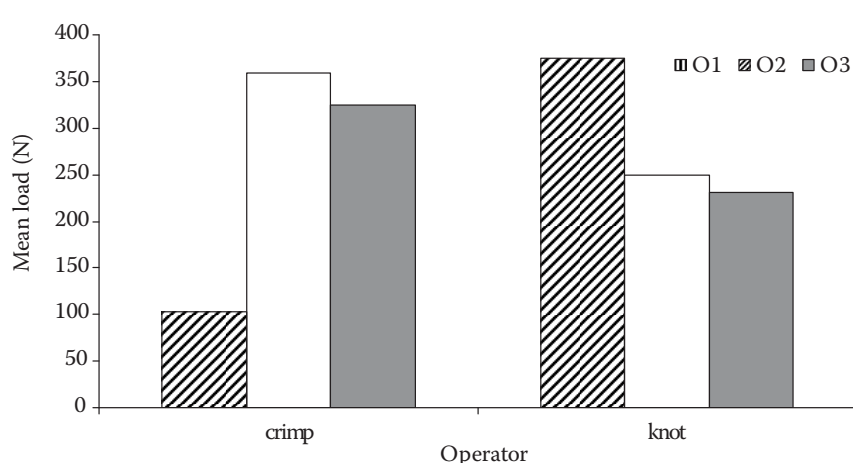Figure 2. Tensile loading. MNL = monofilament nylon leader

Figure 3. Load at failure for loops

DISCUSSION

Cranial cruciate ligament rupture is the leading cause of canine stifle instability (Johnson and Johnson 1993). The CCL functions to limit cranial tibial translation, internal rotation of the tibia, and hyperextension of the stifle (Vasseur 2003). The goal of surgical stabilisation is to restore normal joint kinematics and prevent or inhibit secondary changes such as degenerative joint disease (Vasseur and Berry 1992). An optimal treatment for canine stifle stabilisation after CCL rupture has not yet been established. Current stabilisation techniques can be categorised as: intracapsular, extracapsular repairs, fibular head transposition, and corrective osteotomies (Vassuer 2003). Currently, the most popular techniques are extracapsular repairs and corrective osteotomies. Extracapsular techniques were developed to eliminate the cranial drawer sign and statically stabilise the stifle joint, whereas the goal of tibial osteotomies is to eliminate cranial tibial thrust, which occurs during weight bearing. Our experiences show that the extracapsular method is easy to perform, there are minimal instruments requirement, and we record good postoperative outcome as determined by return to function and radiographic low osteoarthrosis progression. This repair provides temporary stabilisation of the stifle joint while periarticular fibrosis develops which provides long term stability. If the suture loosens or breaks before adequate fibrous tissue forms, the stifle becomes unstable and degenerative joint disease will progress rapidly.

The purpose of this study was to investigate the mechanical properties of different types of suture material, which can be used in the extracapsular method of stabilisation of canine stifle joint with a ruptured CCL. We also investigated the interoperator variation of securing the loop with two different methods of fixation. The ideal orthopaedic material should have high tensile strength, should not be prone to elongation, and must provide good knot security and tolerate the environment where it is supposed to function (Caporn and Roe 1996). It should also have a minimal negative effect on the surrounding environment (Carr et al. 2009). For years, the MNL has been the suture material possessing all these desired properties. All materials were in sterile packaging when purchased, so the sterilisation method used did not have any influence on our study. It was estimated that canine CCL resists load of 50 N at walk and up to 400–600 N during higher activity (Caporn and Roe 1996; Wingfield et al. 2000; Burgess et al. 2010). 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). All materials except Silon exceeded this limit, but none exceeded the estimated highest load. It is important to note that the *in vivo* physiologic forces of the canine cruciate ligament have not yet been defined (Rose et al. 2012). The MNL shows the best mechanical properties and the choice of fixation method of the loop does result in any significant differences. However, Supramid would be a suitable alternative to MNL. The joint forces and load on the suture increases in parallel with increases in the dog's weight.

One of the complications of the extracapsular technique is loop loosening during early post-operative care. The loop can be secured using either a knot or a crimp. The knotting of a large gauge nylon results in a bulky knot. The use of stainless-steel tubes (crimp) is an alternative to knotting. The two

ends of the nylon line are passed through the crimp clamp in the opposite direction and a crimping tool is used to pinch the metal tube and so secure the nylon line. Applying higher pressure on the crimp during fixation can decrease the strength of the suture material. We found that there is no significance difference between crimped loops and knotted loops. In contrast Burgess et al. (2010) stated that 80 lb crimped loops were significantly weaker than knotted loops and two other studies (Peycke et al. 2002; Roe et al. 2008) which evaluated 80 lb MNL found that crimped loops were significantly stronger than knotted MNL. The reason for these discrepancies results might lie in differences in operator grip strength, knotting ability or differences in methodology (Moores et al. 2006).

We recorded a significant difference between the three operators, which might affect grip strength, but all three operators are active surgeons familiar with the use of crimping tools. The significance is probably based on the preference of each operator for either the knot or crimp. Many authors (Anderson et al. 1998; Vianna and Roe 2006) have stated that stifle stability is maintained more effectively by crimped nylon loops compared to knotted loops of MNL, but our experience using knotted loops is based on our higher confidence of stifle stability. Whereas the crimp clamp provides better mechanical performance than knots in larger diameter MNL loops, knotting is the only method for securing Silon and Supramid.

Based on our results, we conclude that MNL 100 lb and MNL 80 lb are mechanically superior to Silon and Supramid. The method of loop fixation depends on the preference of the surgeon. Extracapsular stabilisation is an effective method for surgical treatment of cranial cruciate ligament rupture in dogs. We have very good results with extracapsular stabilisation, and preliminary comparison with other methods shows no differences. In general, multifilament braided materials have good material properties (load to failure, stiffness, knot security), while monofilament materials allow crimp fixation, and are associated with low risk of infection and tissue reaction.

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