Biomechanical analysis of a ligament fixation systems for CCL reconstruction of rupture cruciate in a canine cadaver model.

B. Goïn, P. Rafael, Q. Blanc, P. Buttin, T. Cachon, C. Carozzo and E. Viguier

Aix-Marseille Université, CNRS, ISM, Marseille, France; VetAgro-sup, Unité ICE, Lyon, France

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1. Introduction

Recently, in veterinary medicine a new technique of intra-articular repair is receiving increasing attention, particularly when using prosthetic ligaments [1]. The development of such technique is encouraged by a need for easy and simple surgical procedure, and the availability of new resistant ligaments made of high-density polyethylene. However, all intra-articular techniques suffer from weakness of the anchoring of the ligament in the immediate postoperative but also in the postoperative during the first months. Various fixing solutions have been developed both in animals and in humans. The interference screws are the gold standard [2].

The aim of this study was to test static and dynamic biomechanical properties of ruptured CCL repair with an ultra-high molecular weight polyethylene (UHMWPE) prosthesis fixed with 4 interference screws on ex-vivo dog knee joints. We hypothesized that:
- The values of the maximum resistance (M,) load for this LCL stabilisation would be at least similar of those of the natural ligaments.
- The initial slipping (L,) strength would be superior to normal walking and trotting conditions during immediate postoperative period.
- This high strength could be maintained during 100,000 cycles corresponding to the 2 months of post operating with walking and trotting.

2. Methods

2.1 Preparation of samples

Height hindlimbs from 6 adult dogs between 25 and 35kg were taken. Dogs were of similar size and died from reasons unrelated to this study. Knees were dissected to let intact only tibia, CCL and femur. Each extremity of the bones was fixed with resin onto two supports.

2.2 Implantation of the UHMWPE ligament

After realization of the quasi static tensile test of rupture on the native CCL, the knee has been implanted with a UHMWPE ligament (Novatig, Novetech, Monaco). The rest of CCL were removed. An oblique tibial tunnel was drilled from the cranio-medial insertion of CCL. A femoral tunnel was drilled from the caudo-lateral femoral insertion. The ligament was passed through the 2 tunnels. A first interference screw (diameter: 4.5mm, 20mm-long) was inserted outside to inside the articulation from the distolateral femoral metaphysis. After straightening the ligament, a second interference screw was inserted outside to inside from the proximo-medial tibia. Each extremities of the ligament were secured. Two transverse tunnels were preformed to fix each tight extremity of the prosthesis with femoral and tibial interference screws.

2.3 Biomechanical testing

Static and dynamic tensile tests of the CCL were performed on embedded knees using a traction system (AGS-X Shimadzu, Japan) with in a pretest of 20mm/s traction until the strength reached 10N, straightening the system. The first static test consisted in a 1mm/sec traction to failure. Failure was considered if the displacement reached 40mm. The knees stabilized with the polyethylene ligament and the 4 interferences screws were prepared to dynamic test. A pretest of 20mm/s traction until the strength reached 10N (i.e. the initial tension). The dynamic rate was 0.58Hz during 100,000 cycles, bounding with two values, a minimum of 100N of pretension and a maximum of 210N (195N + 15N of safety) corresponding of the strain undergone by the CCL during trotting [3]. For the two series of tests, sampling rate for data acquisition was set at 10Hz. A total of 8 experimental set-ups were considered: 5 under quasi-static condition (8D, 11D&G, 13D&G, Fig.1) and 3 under dynamic condition (15D, 16D, 17D, Fig. 2).

2.4 Data acquisition and processing

During tests, acquisitions of the data were carried out using the TrapeziumX software (Shimadzu, Japan). The data-processing was performed with Matlab (Massachusetts, USA). Mean curves were obtained by applying a two-way average moving filter (window size: N=500).

3. Results and discussion

Quasi-static results are provided in Fig. 1. No rupture of the set-up occurred. Though, an initial flip strength I = 309N ± 151N (mean ± sd) of the prosthesis was observed at 3.78mm ± 2.22mm. Then, the maximum resistance M = 800N ± 132N was reached at 24.4mm ± 8.73mm. No significant difference was observed between M, sound ligaments and M, artificial ligaments (Matlab ttest, P = 0.87).
All the set-ups including a prosthesis implanted with 4 interference screws gave Is higher than the strength applied to the CCL during walking in dogs (90N). Besides, 4 out of the 5 tests were also higher than strength while trotting (210N). Lastly, M values were 1.54 to 4.27 times higher than Is values. Sliding can be explained via two ways. First, it could be due to an incorrect implantation of interference screws, thus resulting in cancellous bone injury or abnormal compression of the ligament against the cancellous bone. The second reason could come from the insertion of the ligament prosthesis into the intra-articular subchondral part of both the femoral and tibial bone tunnels.

Dynamic investigations are displayed in Fig. 2. During the dynamic tests, the 100.000 cycles last for 48h and simulated typical locomotive motions. Distinct behaviors were outlined. Two of them exhibited similar responses (15D and 17D), for which the Is values remain for 5h until the establishment of a plateau at 0.7mm and 2.22mm respectively. Then, the displacement remains insignificant for the last 43h. The 16D set-up shows a different behavior, including a resumption of the sliding (approx. 2.5mm) at 37h. X-ray examination reveals the implantation of the oblique femoro-distal and tibio-proximal screws in the growth cartilage. Cancellous bone properties within the growth zone are known to be poor because it is not yet organized or mineralized. During the 5 first hours, the displacement observed in 16D set-up can be explained by an incorrect pre-tension of the prosthesis at the interference screws implantation phase which allows an initial flip of the set-up. Obviously, a dynamic test including 100.000 cycles is far beyond what a dog is expected to face in post-operative conditions. This would correspond to a dog trotting for at least 75km in less than 48h.

4. Conclusions
In veterinary surgery of the ruptured CCL, this new system of stabilisation has no significant difference with the native ligament for the Mr load slipping. The Is is superior to the strength of normal walk and very close to those of trotting. In the light of these biomechanical results, this new system could offer to adult dogs a good and secure stabilization of the knee with the usual post operative restriction of locomotion during the two months post operative period. This time is necessary to boost both fibrous and osseous integration of the ligament.

References

*Corresponding author. Email: eric.viguier@vetagro-sup.fr*