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Investigation of knee joint stability in surgically repaired canine cruciate ligament ruptures by cyclic passive joint motions

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Abstract: The cranial cruciate ligament (CCL) rupture is a prevalent injury in dogs. A consequence of a cruciate ligament rupture is instability in the affected knee joint. A veterinary, mostly surgical treatment of the cruciate ligament rupture is usually unavoidable. The suitability of an arthroscopic surgical method with ligament replacement material was investigated. The stability of the knee joint was determined several times during 1,200 passive robotic motion cycles with movement radius between 90° flexion and 140° extension. The stability condition was measured by triggering the drawer test. After 300 motion cycles, the drawer test could be triggered (positive drawer test). In the following movement cycles up to 1,200 cycles, the drawer test could also be triggered. However, no significant differences occurred between these triggered drawer tests. The ligament replacement material showed no damage and no loosening after the tests. The first results showed that the developed arthroscopic surgical method could be a promising approach for the surgical treatment of cruciate ligament ruptures in canines.

Keywords: Cranial cruciate ligament, Robotic cyclic passive joint motions, Drawer test, Cruciate ligament ruptures, Canine, Ligament replacement material

1 Introduction

About eight million dogs live in Germany. Cranial cruciate ligament (CCL) rupture is one of the most common injuries in dogs [1]. Most cruciate ligament ruptures are the result of a weakened ligament, caused by wear and tear, degeneration, but also by breed disposition of the dog [2]. Rupture of the CCL can occur in relation to abrupt rotation during slight flexion of the knee joint, for example during a sudden turn with a limb fixed to the ground, or as a result of violent hyperextension, such as kicking into a hole during rapid locomotion. With increasing frequency, however, minor traumas are sufficient, since most ruptures occur based on degenerative previous damage to the CCL [3]. The rupture of the cruciate ligament can therefore be diagnosed with a sensitivity of 96 % using the so-called drawer test [4]. Thereby, the femur is held in place while the tibia is shifted forward and backward. In a normal, stable joint, there will be little to no motion, but a rupture of the cruciate ligament allows the tibia to slide forward. Therefore, a positive drawer test is indicative of cruciate ligament damage [4]. A veterinary, mostly surgical treatment of the cruciate ligament rupture is usually unavoidable. Currently, there is a variety of different surgical methods available for the treatment of cruciate ligament ruptures [5,6]. A modification of the arthroscopic surgical method with ligament replacement material according to [6] was performed by fzmb GmbH. The suitability of this method will be investigated in this paper. Validation of surgical methods is performed using cyclic passive knee joint motions [5]. These are usually performed manually and are therefore limited in number of motion cycles and accuracy. In the investigations underlying this paper, the cyclic passive knee joint motions will be performed with the help of a robotic arm followed by a defined drawer test.

2 Methods

A two-stage procedure was used to determine knee joint stability [5]. Firstly, the canine knee joints were prepared and divided into three conditions (I: CCL intact, II: CCL severed, III: CCL severed and surgically repaired). Secondly, a stability investigation of the three conditions was performed as well as simulation of knee joint motions with a fixed number of motion cycles for condition III followed by a fixed

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defined drawer test. The drawer test was performed five times for each motion cycle and statistically analysed (mean, standard deviation, and normalization).

2.1 Specimen preparation

Stability testing of the surgical method was performed on cadavers of dogs that died naturally or were euthanized for medical reasons that did not affect the hind limbs or related structures (Veterinary Clinic Bad Langensalza, GER). For this purpose, the hind limbs were separated at the hip joint and the thigh muscles were removed for the study. Only the joint capsule and the lower leg musculature remained intact. The specimens were frozen at -24 °C until further use. The average age of the dogs was 8 ± 4 years. Body mass ranged from 20 to 35 kg. A total of 24 hind limbs were examined (n = 10 CCL intact, n = 10 CCL severed, n = 4 CCL severed and surgically repaired). Twelve hours before examination, the limbs were thawed at room temperature.

2.2 Experimental Setup

After thawing, the hind limbs were first fixed in a clamping device. This consists of a vertical plate and two pipe clamps positioned at 10 cm from the plate and 12 cm from each other. The femur was fixed with the pipe clamps parallel to the plate. The lower leg, tarsus and paw remained unfixed (see Figure 1a) [5].

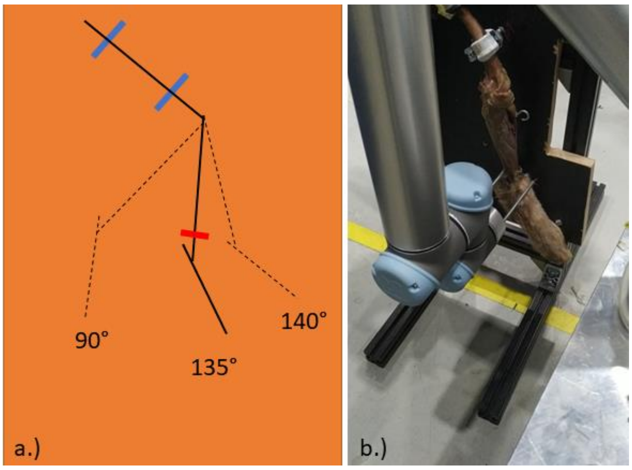

Figure 1: a.) Schematic representation of hind limb fixation (blue - pipe clamps, red - robot gripper attachment, dashed line - lower leg position at 90° flexion and 140° extension) [5] and b.) experimental setup with robot arm and clamping device.

The pipe clamps on the plate were positioned to ensure that the knee joint had a residual opening angle of 135° as caused by gravitational force. A metal eyelet was screwed into the tuberosity to perform the drawer test. The same metal eyelets were used for all 24 specimens. The orientation of the eyelet was set horizontal and parallel to the plate [4,5].

Subsequently, the clamping device was mounted in a 4-column testing machine to conduct the drawer test. While the femur was firmly fixed in the clamping device, a tensile with defined force (F = 20 N) in cranial direction could be applied to the tibia using the eyelet. The maximum measurable displacement of the tibia at applied tensile force describes the instability of the knee joint (see Figure 2).

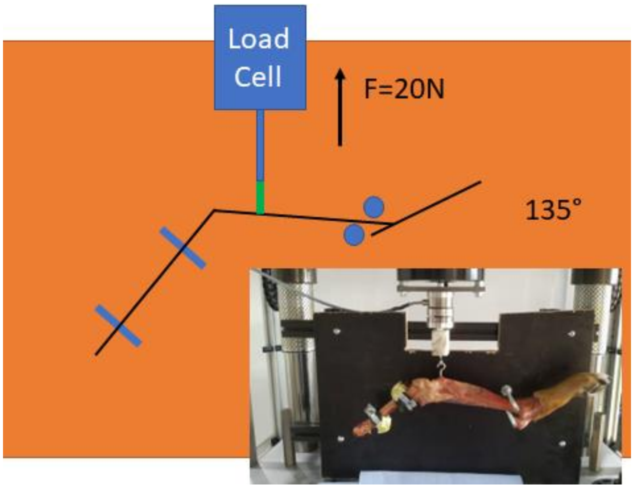

Figure 2: Schematic representation of hind limb fixation for the defined drawer test (blue - pipe clamps, green - metal eyelet for connection to the load cell) [5].

After performing the drawer test, the device was removed from the 4-column testing machine and mounted on a frame for performing the cyclic passive knee joint motions. Passive flexion and extension of the knee joint with v = 60 °/s and a = 80 °/s² were performed using a robot (Universal Robots, UR5, GER). For this purpose, the robot gripper was attached to the tarsus of the hind limb. The lower leg was moved parallel to the plate and a motion radius of 90° flexion and 140° extension was maintained (see Figure 1a and b) [5]. The programming of the motion path was executed with the integrated software. The drawer test was performed after 0 (Z0), 50 (Z50), 100 (Z100), 300 (Z300), 600 (Z600) and 1,200 (Z1200) motion cycles for determining the instability of the joint.

2.3 Execution of experiments

Firstly, the drawer test was performed for condition I (n = 10). Secondly, the canine knee joints were prepared for condition II (n = 10). For this objective, the joint capsule was opened and the CCL was severed and resealed with a single-stitch suture. The drawer test for condition II was performed afterwards. For condition I and II, no cyclic passive knee joint motions were performed. Lastly, the canine knee joints were prepared arthroscopically for condition III (n = 4). For this purpose, the CCLs were severed and the ligament replacement material (Zlig, EICKEMEYER®, GER) was implanted by using the surgical method [7]. After implantation, the joint capsule was re-closed with a single-stitch suture. For condition III, a drawer test was performed after a Z motion cycle. For all conditions, five drawer tests per knee joint and a Z motion cycle for statistical analysis were performed.

2.4 Arthroscopic surgical method

The procedure of the arthroscopic surgical method can be described as follows. The knee joint preparation is identical to the procedure for a standard knee joint surgery. The optic is placed via a craniolateral port lateral to the straight patellar ligament between the patella and the intercondylar trochlea. The outflow cannula is placed proximal medial to the patella. The joint is dilated and irrigated via an irrigation pump throughout the procedure.

After triangulation, the working channel is placed medial to the straight patellar ligament. This is followed by the setting of the femoral drill channel (see Figure 3a).

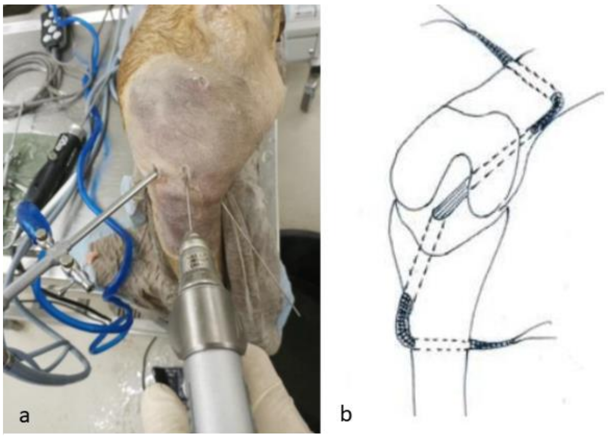

Figure 3: a.) Setting of the femoral drill channel and b.) Schematic representation of the cruciate ligament implant course with transverse drilling for additional fixation [6,7].

It conducts intra-extraarticular in a proximal-lateral direction. The tibial channel is placed extra-intraarticularly in the distal cruciate ligament insertion on the tibial plateau. The distal end of the drill channel is placed at least 2 cm below the joint edge and approximately 1 cm medial to the tibial tuberosity. The ligament implant is then advanced into the knee joint with a guide wire through the femoral drill channel and guided out through the instrument port until the knotted portion of the implant extends into the joint. The implant is fixed laterally to the femur and then tightened manually. A ligament that is too tight should be considered the critical factor, as this can provoke implant failure. To check the correct placement of the implant, the leg is then incautiously moved from total flexion to full extension. If the drilling is isometric, the implant does not move in the tibial drilling channel during this procedure. According to previous estimates, a tolerance of 1 - 2 mm can be granted here, which would correspond to a slight deviation from isometry. The implant is then fixed medially in the tibia with a screw (Königsee Implantate GmbH, GER). Subsequently, a transverse drill channel is made tibial and femoral at about 10 mm from the first drill channel and the implant is pulled through to fix it with another screw in each case (see Figure 3b). This helps to additionally secure the implant against slipping out of the fixation [6,7].

3 Results

The results from the drawer tests for condition I, II, and III are shown in Figure 4 and 5. The results are normalized to the displacement of condition II.

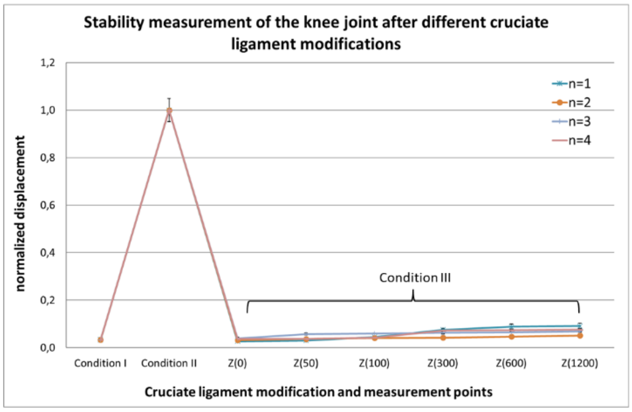

Figure 4: Stability measurement of the knee joint with different modifications (Condition I and II: n = 20, Condition III: n = 4).

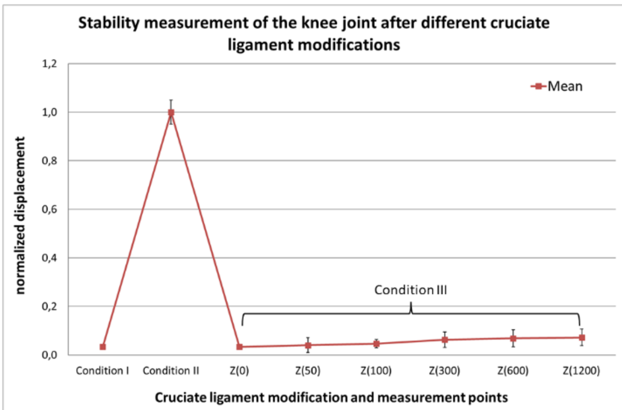

Figure 5: Stability measurement of the knee joint with different modifications (mean).

It is evident that the drawer test was triggered at condition II. For condition III, a triggering of the drawer test could be registered after 300 motion cycles (Z300). In the following movement cycles up to 1,200 cycles, the drawer test could also be triggered. The measured displacements of the tibia for motion cycles Z600 and Z1200 showed no significant differences from the measured displacement for motion cycle Z300. Between negative and positive drawer tests, the change in the measured displacement of the tibia was approximately 50 %. The triggering of the drawer test could be caused by the setting of the fixing screws. A critical factor could also be the manual tightening of the implant since both, a too tight and a too loose implant can lead to joint instability. If the implant is too tight, failure of the implant material may occur. If, on the other hand, the implant is too loose, the loosening of the implant may increase because of the greater joint clearance [8,9]. After completing the tests, no loosening of the fixing screws could be detected. Furthermore, the ligament replacement material also showed no damage.

4 Conclusion

The suitability of the arthroscopic surgical method with ligament replacement material was investigated using robotic cyclic passive knee joint motion. A triggering of the drawer test was found after 300 cycles of motion. However, no significant increase in displacement of the tibia occurred up to 1,200 cycles. The robotic knee motion is not limited in the number of motion cycles and achieves a very good repeatability and accuracy, which could never be performed manually [10]. Furthermore, the kinematic frame conditions can be adjusted individually [11]. The implant material showed no damage or loosening after the tests. The first results show a promising method for the treatment of cruciate ligament ruptures in canines. However, further studies need to be conducted to confirm the results. Thereby, the number of cyclic passive knee motions should be increased.

Author Statement

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