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# Intra-articular Pressure Changes during Stifle Arthroscopy Using a Cadaver Model

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## Abstract

**Objective** The aim of the study was to measure canine stifle intra-articular pressures (IAP) during arthroscopy using three different fluid pump pressure (FPP) settings.

**Study Design** Frozen thawed canine cadavers were used. The stifle was distended using a 2.7 mm arthroscope connected to a commercial fluid pump. Intra-articular pressure was measured using a portable pressure gauge connected to an intra-articular 18 G needle. Intra-articular pressure was recorded during stifle extension, 90 degrees flexion and full flexion at three different FPP (30, 50, 80 mm Hg).

**Results** Testing was performed on 27 stifles. Intra-articular pressure significantly increased at higher FPP ($p < 0.01$). At FPP 30, 50, and 80 mm Hg, the mean IAP was 51.8 (95% confidence interval [CI]: 41.3–62.2), 103.3 (95% CI: 92.8–113.7), and 175.2 mm Hg (95% CI: 164.8–185.6), respectively. At FPP 30 and 50 mm Hg, IAP always remained under 170 mm Hg. At 80 mm Hg, IAP raised to or above 170 mm Hg in 11/14 stifles. Stifle position significantly affected IAP ($p < 0.01$). Changing stifle position from 90 degrees flexion to extension significantly decreased IAP by 22.4 mm Hg (95% CI: 16.2–28.5), and changing to full flexion significantly increased IAP by 20.9 mm Hg (95% CI: 14.8–27.1; $p < 0.01$).

**Conclusion** Our results suggest that caution should be used during stifle arthroscopy to limit risk for iatrogenic capsular damage. Fluid pump pressure 30 mm Hg is considered safe when using a 2.7 mm arthroscope and high flow cannula. If higher FPP is necessary for visualization, duration of stifle flexion should be limited. Fluid pump pressure 80 mm Hg should be avoided.

**Keywords**
- joint surgery
- orthopaedic surgery
- stifle joint
- cranial cruciate
- ligament injury
- dog

## Introduction

Cranial cruciate ligament injury is the most common surgical orthopaedic condition in dogs leading to stifle instability.[1] In dogs in both cadaver models and the clinical setting, arthroscopy is superior to an arthrotomy for the detection and subsequent early treatment of even small meniscal tears due to improved visualization of intra-articular structures through magnification.[2–4] Arthroscopy has also been shown to result in higher postoperative patient comfort and an earlier return to function than patients recovering from an arthrotomy.[3]

Despite arthroscopy being gold standard for intra-articular inspection, canine studies investigating the safety of commercial fluid pump pressure (FPP) systems are lacking. Fluid pump pressure is routinely set at 50 mm Hg during canine stifle arthroscopy based on previously reported normal intra-

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articular pressures (IAP) reaching up to 50 mm Hg during stifle range of motion in standing and anaesthetized dogs.[5,6] Investigations into commercial FPP systems in humans have shown significant differences between the target IAP and delivered IAP, with FPP settings of 50 mm Hg producing IAP measurements of up to 160.44 mm Hg.[7,8] Viscoelastic studies of the human knee joint capsule have shown that at 120 mm Hg IAP, the joint capsule retains its viscoelastic properties.[8] The yield point for plastic deformation of the joint capsule in humans without capsular rupture has been reported to be 170 mm Hg.[8] In dogs, brief pressures of up to 300 mm Hg are tolerated by the cadaver joint capsule without capsular rupture, and therefore in vivo, an intact joint capsule cannot be used as an indicator of safe arthroscopy, as non-visible permanent capsular deformation may have occurred.[9]

The aim of this study was to measure IAP during stifle joint arthroscopy using different FPP settings to determine if the pump settings currently used in veterinary medicine exceed IAP values known to cause permanent plastic deformation of the joint capsule. We hypothesize that increasing the FPP settings will lead to a higher IAP, but that stifle position during arthroscopy would not have a significant effect on the IAP.

## Materials and Methods

Fourteen frozen canine cadavers euthanized for reasons unrelated to this study were thawed to room temperature. The cadavers selected were of similar size, estimated between 20 and 25 kg, to standardize joint volumes.[6] Cadavers were excluded if they had palpable or arthroscopically visible orthopaedic disease of the stifle joint.

Intra-articular pressures were measured modelling the methods by Galvin and colleagues using an intra-articularly placed 18G needle linked to an extension set connected to a portable pressure gauge.[10] The system was calibrated using sterile saline connected by a three-way stopcock to the extension line.[10] An 18G needle connected to the pressure gauge system was inserted into the medial joint compartment to measure the baseline pressure. The joint was then distended with 10 mL of saline and the first pressure measurement taken. A medial parapatellar joint portal was made medial to the patella tendon as a stab incision with a #11 blade approximately halfway between the distal pole of the patella and proximal tibial joint line. A high flow egress cannula (Clearvu 2.7, Cannuflow, California, United States) was placed through the medial portal into the joint compartment and directed proximally exiting the joint proximomedially through a separate stab incision made over the egress cannula. A 2.7-mm 30- degrees arthroscope (Stryker, Michigan, United States) was inserted into the joint via a standard lateral portal created with a #11 blade and connected to a xenon light source and Arthrex Continuous Wave II arthroscopy fluid pump AR-6400 (Arthrex, Florida, United States) at 70% fluid flow. Intra-articular pressure measurements were taken serially at stifle extension, standard scoping position of 90 degrees flexion and full flexion. The FPP settings were sequentially increased from 30 to 50 mm Hg to 80 mm Hg. The IAP measurement was taken once readings stabilized after the initial peak at the new FPP setting.

Statistical analysis was performed using a mixed effect model using SPSS software (IBM, New York, United States). Fixed effects were included for stifle position (flexion, 90 degrees flexion, extension), FPP (30, 50, and 80 mm Hg) and patient's stifle (right, left). A random intercept was included for the cadaver to account for multiple measurements on the same cadaver. Confidence interval (CI) was reported at 95%. Significance level was set at $p$-value less than 0.05. Pairwise comparisons were performed for stifle position and FPP after fitting the mixed effects model.

## Results

Fourteen canine cadaver specimens with normal stifle joints were used. Bilateral measurements were taken in stifles of 13 dogs. Unilateral measurements were taken in one case. One stifle was excluded due to data collection error during testing. Right and left stifles had significantly different IAP readings, with stifle pressures 5.3 mm Hg (95% CI: 0.2–10.5) lower in the left than right stifle ($p = 0.042$).

### Effect of Pump Pressure Setting on Intra-Articular Pressure

Stifle distension with 10 mL saline increased IAP to a mean of 26.5 mm Hg (95% CI: 11.8–41.2). Intra-articular pressure was significantly higher at higher FPP ($p < 0.01$). During arthroscopy, regardless of stifle position, FPP set at 30 mm Hg resulted in mean IAP of 51.8 mm Hg (95% CI: 41.3–62.2). Pairwise comparison revealed that increasing the FPP from 30 to 50 mm Hg significantly increased IAP by 51.5 mm Hg (95% CI: 44.7–58.4, $p < 0.01$) to a mean IAP of 103.3 mm Hg (95% CI: 92.8–113.7). When FPP was increased from 50 to 80 mm Hg, the mean IAP significantly increased by 71.2 mm Hg (95% CI: 63.2–80.6, $p < 0.001$) to a mean of 175.2 mm Hg (95% CI: 164.8–185.6). Increasing the FPP from 30 to 80 mm Hg resulted in a significant IAP increase by 123 mm Hg (95% CI: 117.3–129.6) ($p < 0.01$; ►**Fig. 1**).

At a FPP setting of 30 mm Hg, the stifle IAP always remained under 120 mm Hg (81/81 trials; ►**Fig. 2**). Stifle IAP remained under 120 mm Hg in most trials at 50 mm Hg (63/81), with IAP increasing above 120 mm Hg only during flexion in all except two stifles (25/27). When the FPP was set at 80 mm Hg, most trials (73/81) measured an IAP above 120 mm Hg. At 30 and 50 mm Hg FPP, IAP always remained under 170 mm Hg (162/162 trials). At 80 mm Hg, IAP elevated to 170 mm Hg or above during most trials (52/81 trials, 11/14 stifles).

### Effect of Stifle Position on Intra-Articular Pressures

Stifle position during arthroscopy significantly affected IAP readings ($p < 0.01$; ►**Fig. 3**). The mean IAP estimated from our model across all FPP during stifle extension was 88.2 mm Hg (95% CI: 77.8–98.6), increasing to 110.5 mm Hg (95% CI: 100.1–121.0) at 90 degrees flexion, and to 131.5 mm Hg (95% CI: 121.1–141.9) during full stifle flexion. The pairwise comparison revealed that for all FPP, changing stifle position from 90 degrees flexion to full extension significantly decreased IAP by mean of 22.4 mm Hg (95% CI: 16.2–28.5) and

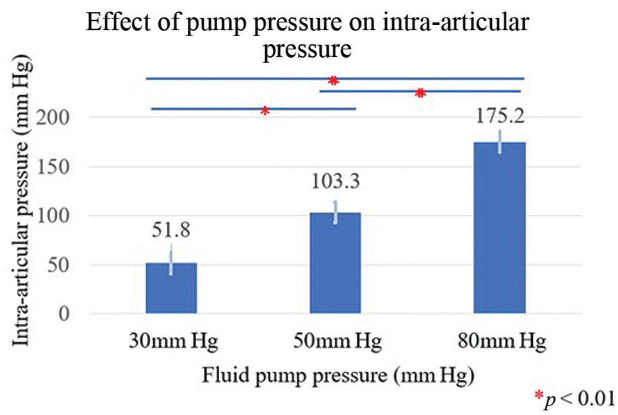


**Fig. 1** Mean intra-articular pressures (with confidence interval at 95%) at different pump settings. Increasing the pump pressure increases stifle intra-articular pressures significantly regardless of stifle position ($p < 0.05$).

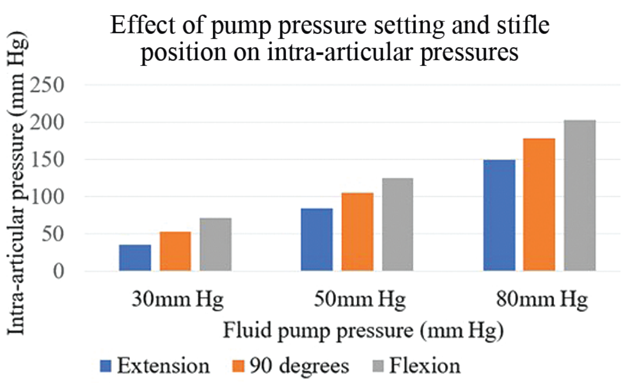


**Fig. 2** Increasing pump pressure settings and flexing the stifle position result in significant intra-articular pressure increases. Significant differences exist between all pump pressure settings and stifle positions ($p < 0.05$). (30 = 30 mm Hg, 50 = 50 mm Hg and 80 = 80 mm Hg fluid pump pressure setting, E = stifle extension, 90 = stifle position at 90 degrees flexion, F = full stifle flexion).

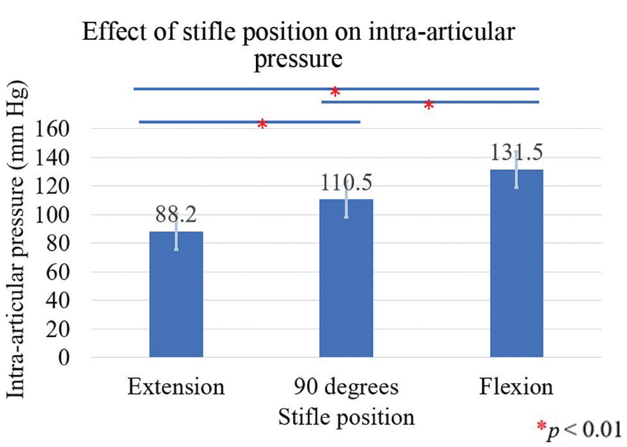


**Fig. 3** Mean intra-articular pressures (with confidence interval at 95%) across all pump pressure settings during different stifle positions. Changing stifle position from extension to flexion significantly increases stifle intra-articular pressures ($p < 0.05$).

full flexion significantly increased IAP by mean of 20.9 mm Hg (95% CI: 14.8–27.1; $p < 0.001$).

## Discussion

We accept our hypothesis that increasing FPP settings results in higher IAP measurements. An essential requirement of successful stifle arthroscopy is adequate visualization of the intra-articular structures; this is often achieved by increasing FPP settings. However, excessive IAP may exceed the yield point for permanent plastic deformation of the joint capsule or even result in catastrophic capsular rupture leading to fluid extravasation. The human knee joint capsule has been reported to retain its capsular viscoelasticity at 120 mm Hg; however, increasing IAP to 170 mm Hg has been shown to cause permanent non-visible capsular deformation despite maintaining an intact joint capsule. Extrapolating the established safety limit of maintaining IAP under 120 mm Hg to dogs, this was not exceeded using the 30 mm Hg FPP setting; however, when increasing the FPP to 50 mm Hg, most stifles exceeded this limit during stifle flexion, and almost all at 80 mm Hg regardless of stifle position. In this study, the IAP always remained under the in humans reported 170 mm Hg non-visible capsular deformation threshold at 30 and 50 mm Hg FPP settings, regardless of stifle position. At 80 mm Hg most stifles measured an IAP at or above 170 mm Hg. We can therefore conclude that 80 mm Hg FPP settings should be avoided during canine stifle arthroscopy. The use of 50 mm Hg should be done with caution, as despite the IAP remaining less than 170 mm Hg, the 120 mm Hg safety limit was exceeded during most trials during stifle flexion. It is important to recognize that this conclusion is extrapolated from human data, and that information regarding the viscoelastic properties of the joint capsule between 120 and 170 mm Hg IAP is lacking in dogs. To the authors knowledge, there is no published data on the maximal IAP that is tolerated without deformation of the canine stifle joint capsule and histopathological changes of the joint capsule undergoing elastic and plastic deformation have not been studied to date.

We reject our hypotheses that changing stifle position do not significantly alter IAP during arthroscopy. During canine stifle arthroscopy, the joint is brought through range of motion to allow for visualization of all stifle compartments. We confirm that as previously reported, joint position change from extension to flexion increases stifle IAP in dogs.[5,9] Although the change is significant, a 20 mm Hg change in IAP is not considered clinically relevant unless a high FPP is concurrently used, as brief pressures of up to 300 mm Hg have been shown to be tolerated without capsular rupture in dogs.[9] If higher FPP is used, caution should be used to limit the duration of stifle flexion to avoid causing iatrogenic capsular changes.

We suspect that minor, although significant differences in IAP laterality were due to the surgeon's hand dominance resulting in slightly smaller portal size and less portal extravasation in the left stifle. Extravasation during stifle arthroscopy leading to cadaver exclusion did not occur. This was minimized by using a high flow egress cannula, and by increasing FPP sequentially instead of randomization. Sequential repeated intra-articular joint distension by the FPP may have affected the joint capsule's plasticity and resulted in artificially low readings for higher FPP. The sequential order and repeated measurements were, however, considered when forming the statistical model used for analysis.

The FPP settings investigated in our study were selected to remain within the range used in clinical practice; however, additional FPP settings and pump systems could have also been investigated. Surgeons should be aware that, as supported by our study results, the delivered IAP may be significantly higher than set on the pump. Some caution should, however, be used when translating the results of our study across to other fluid pump systems as significant differences in the accuracy of pump settings and IAP delivery exist.[7,11–13] The clinical importance is that surgeons should have an awareness of the properties of the pump system used, and they should readily adjust the FPP delivery settings to the lowest level while still permitting adequate visualization, rather than only rely on a pre-established setting across all fluid delivery systems.[7,13]

The main major limitation of this study is the use of a cadaver model, with dogs of unknown clinical history. The use of in vivo models, however, could not be justified due to studies supporting large variations between pump systems and subsequent IAP measurements during arthroscopy.[7,11–13] Frozen-thawed equine distal limbs have been demonstrated to accurately retain in vivo joint capsular properties and IAP, and therefore, similarly stored and thawed specimens were used in our experiment.[14] In our study, stifles included were free from palpable and arthroscopic orthopaedic disease, which may have influenced joint distension properties when comparing to inflammatory arthritic cruciate deficient joints.

In conclusion, caution should be used during stifle arthroscopy when using higher FPP to limit the risk for causing iatrogenic capsular damage. Fluid pump pressure settings of 30 mm Hg may be considered safe during stifle arthroscopy when using a 2.7 mm arthroscope and high out-flow cannula. If higher FPP settings are necessary, the duration of stifle flexion should be limited. Pump pressure settings of 80 mm Hg should be avoided to limit the risk for permanent capsular deformation.

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**Conflict of Interest**
None declared.

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