Musculoskeletal modeling: Multicausal ACL rupture variables recognized using dog CCL rupture cases

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Abbreviations

ACL: Anterior cruciate ligament
CCL: Cranial cruciate ligament
PL: Patellar luxation
MPL: Medial patellar luxation
AOI: Angle of inclination
FAA: Femoral anteversion angle
ESN: Early spay/neuter
TPL: Tibial plateau angle

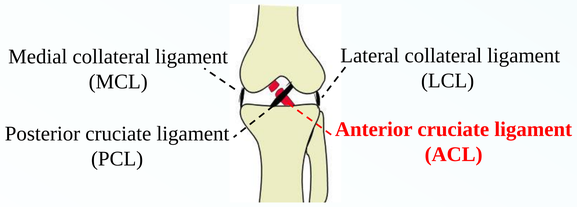
Focus

This study used dogs as an anatomical model to better understand unequal anterior cruciate ligament (ACL) rupture in humans by examining several variables cited as potential rupture factors.

Background

The anterior cruciate ligament (ACL) in humans and the cranial cruciate ligament (CCL) in dogs are homologous structures both susceptible to rupture and regularly result in secondary osteoarthritis. Human musculoskeletal problems are the third highest medical cost in the United States with $170 billion spent annually and only about 50% of people fully returning to their pre-injury, competitive level after surgery (Arden et al., 2012, 2014; Kvist et al., 2005; Langford et al., 2009; Swart et al., 2014).

It is well cited that women are more likely than men to rupture this knee stabilizing ligament (Arendt and Dick, 1995; Haida et al., 2016; Hewett et al., 2006, 2010; Ruedl et al., 2011; van Diek et al., 2014). Concurrently, different dog breeds exhibit unequal rupture rates, which make them appropriate anatomical models to better understand increased rupture risk factors.

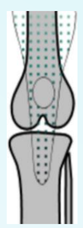


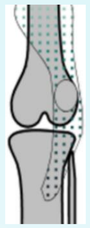
Methodology

This study analyzed random data collected from a veterinary hospital comparing arbitrary CCL ruptured cases (16 females, 13 males) and arbitrary non-ruptured cases (19 females, 9 males). The veterinary hospital provided the osteometric measurements of clinically recorded variables and radiographic assessments

A multicausal approach was used and coding the tibial plateau angle (TPA), patellar luxation (PL), breed, sex, and reproductively intact status. The TPA was only available and therefore only coded for the surgical cases. While femoral anteversion angle (FAA) and angle of inclination (AOI) are possible factors, they were not available for this study.

Methodology

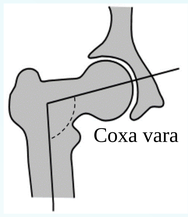


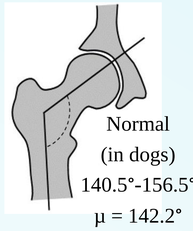


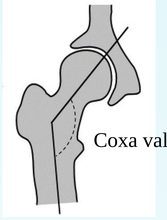
Patellar luxation (PL): joint stability condition when the patella is displaced from the trochlear groove.

Two forms: medial and lateral which, which can occur unilaterally or bilaterally. Medial is more common (MPL) (Gibbons, 2006).

Four severity grades (grade I is least severe): more severe, the higher CCL rupture chance (Campbell et al., 2010).

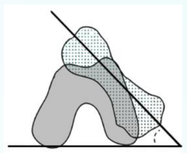




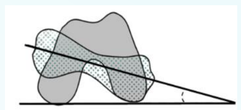


Angle of inclination (AOI): angle of femoral head into the acetabulum in reference to the femur shaft. Normal angle in dogs is 142.2°

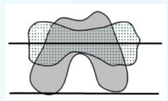
Three forms and degree ranges vary based on measurement techniques (Hauptman 1983; Hauptman et al., 1979; Rumph and Hathcock, 1990; Tomlinson et al., 2007).



Anteversion
Femoral neck is angled anteriorly



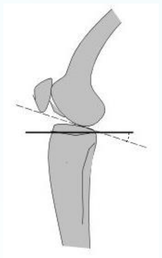
Normal



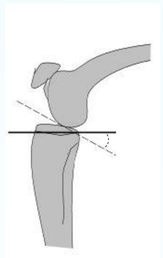
Retroversion
Femoral neck is angled posteriorly

Femoral anteversion angle (FAA): angle of the femoral neck relative to the mediolateral angle of the condyles. Humans are born with a 30° average that decreases to about 14° around 18-20 years (Bråten et al., 1992; Gulan et al., 2000; Kaiser et al., 2001).

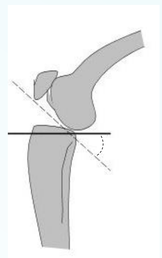
In dogs, puppies have a 0° angle and increases to about 27° (Kaiser et al., 2001). Both can vary widely due to measurement techniques.



Normal: 22.5°



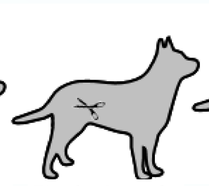
Rupture: 23.5°-28.5°



Excessive (eTPA): >34°

Tibial plateau angle (TPA): angular measurement between the tibial plateau and a perpendicular reference line. Tibial plateau leveling osteotomy (TPLO) is the most common CCL surgery and changes the TPA to produce a more stable joint (Bergh, 2014; Christopher et al., 2013; Shahar and Milgram, 2006).

Fixed – 8 weeks



Fixed – 6 months

Intact - adult

Early spay and neuter (ESN): dogs spayed/neutered at or before 6 months seem to be more prone to CCL rupture (Hart et al., 2016).

ESN dogs have extended growth in the radius and ulna compared to intact dogs. The rate of growth is the same, but plate closure time is delayed in ESN thought to be due to the absence of gonadal hormones (Salmeri et al., 1991).

Results

	CCL Ruptured Cases	Non-CCL Ruptured Cases
Total cases	29	28
Reproductively Intact*	4	21
Sex ratio**	.81	.47
Mean age (years)	5.7	4.6
Mean weight (kg)	33.0	19.8
Mean TPA	25.9°	-
PL cases	0	1

*Statistically significant ($X^2 = 21.7$, $p<0.01$).
**Not statistically significant ($X^2 = 0.97$, $p>0.01$).

These results show large breed, non-intact dogs with abnormal TPAs are more likely to rupture their CCL, suggesting hormonal removal is important in bone and ligament development in dogs and feasibly in humans.

Conclusion

The ACL has estrogen receptors and estrogen influences type I collagen production by downregulating proliferation (Liu et al., 1996; Pollard et al. 2006; Romani et al., 2003). After puberty, laxity increases in females and decreases in males (Giugliano and Solomon, 2007). The estrogen increase in reproductive aged women may account for the increased laxity in the ligament and higher rupture rate.

Collagen in the dog CCL may not have fully developed in dogs that are ESN and results in an overall weaker ligament. The increased laxity from decreased collagen content may account for why spayed/neutered dogs have a higher CCL rupture rate. **However, in both humans and dogs this is thought to be a multifactorial process and hormones are only one potential factor.**

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