IN VIVO KINEMATICS OF THE CANINE STIFLE

P. Böttcher, J. Rey

Department of Small Animal Medicine, Faculty of Veterinary Medicine, University of Leipzig, An den Tierkliniken 23, 04103 Leipzig, Germany

Introduction

Gait analysis in dogs has traditionally been performed using force plate measurements and/or video based kinematic gait analysis. Both alone or together are powerful instruments to objectively characterise canine gait in-vivo. Whereas force plate analysis represents global limb function, video based kinematic gait analysis provides measurements of limited precision only. Therefore, until today precise estimation of in-vivo joint mechanics could only be performed in research dogs, using more or less invasive procedures such as external fixateurs attached to the limb segments or implanted radiopaque markers (KORVICK et al. 1994, TASHMAN und ANDERST 2003). Today, most of our decisions regarding optimal treatment of the cranial cruciate ligament (CCL) insufficient canine stifle are based on appreciation of global limb function in terms of lameness and radiographically scored osteoarthritis or on in-vitro data objectifying the effect of different methods of stabilization on cranio-caudal stability, contact area or contact pressure. Most would certainly agree that the ultimate goal of any stabilization method would be to restore normal stifle function, which is characterised by its three-dimensional kinetics and kinematics. To overcome the invasive character of the aforementioned methods we propose using maker-less in-vivo fluoroscopic kinematic gait analysis, improving our understanding of CCL pathology and its surgical treatment in dogs with naturally occurring CCL rupture.

Material and Methods

Fluoroscopic gait analysis uses either conventional C-arms (Fig. 1a) or high-power x-ray units (Fig. 1b) to allow for uni- or biplanar fluoroscopic analysis. A biplanar setup is preferred over uniplanar data acquisition as the latter is of limited precision when movements occur along the x-ray beam (medio-lateral plane). This significant methodological limitation can be eliminated using two overlapping x-ray beams, angle to each other (Fig.1c), but doubling radiation exposure, cost and time for data analysis at the same time.

Similar to video-based kinematic gait analysis, high-frequency image acquisition is mandatory, aiming for at least 250 images per second, electronically shuttered to 1/2000 s minimizing motion blur during rapid limb movement. Unfortunately standard C-arms and neither high-power x-ray units allow for such high-frequency image acquisition and therefore have to be upgraded using high-speed video cameras which significantly adds to the cost of the experimental setup. Overall, for a biplanar C-arm based system about 100.000€ and for a high-power biplanar system about 1. 000.000€ have to be expected.

Fig. 1a: Uniplanar fluoroscopic setup using a standard C-arm equipped with a high-speed camera and a canine treadmill.

Fig. 1b: Biplanar setup with two high-power x-ray units equipped with two high-speed cameras.

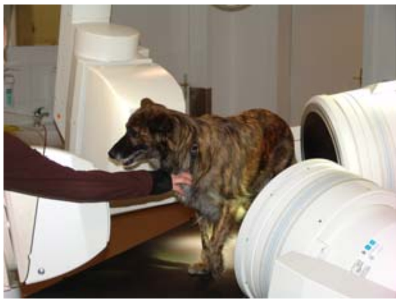

Fig. 1c: Biplanar data acquisition using high-power x-ray units and a canine treadmill.

Because of physical image distortions introduced when using image intensifiers the obtained fluoroscopic image sequences have to be undistorted prior to data analysis. Using XrayProject[#], a set of MATLAB (The MathWorks, Inc.) tools distributed freely by Brown University (BRAINERD et al. 2010), image distortion as well as image calibration are easily performed. Using a piece of perforated stainless steel with known distribution of the perforations the distortions within the fluoroscopic images can be determined automatically and corrected accordingly. Calibration is performed using a cube with 64 radio opaque markers. This way calibration at sub-millimetre accuracy using a direct linear transformation approach is easily feasible.

Once an appropriate image sequence of the stifle has been acquired, undistorted and calibrated, estimation of the 3D-pose of the femur and tibia for each of the frames of the image sequence has to be carried out. This can be done either manually, known as scientific rotoscoping (GATESY et al. 2010), or automatically using 2D to 3D image registration technology. In either way the experimental setup used for data acquisition during gait analysis has to be replicated in virtual space using dedicated software. Based on CT-data of the individual femur and tibia the software generates digitally reconstructed radiographs (DRR) and compares them to the real fluoroscopic images. Depending on the pose of the virtual femur and tibia during calculation of the DRRs the digital and the real images will fit - more or less. Based on this analysis the pose of the bones in virtual space are altered and a new DRR computed and compared at new to the true fluoroscopic image. This process of DRR generation and comparison is repeated until the DRRs and the real fluoroscopic images are identical, meaning that the pose of the bones in virtual space exactly reflects the pose of the bones in-vivo at time of image acquisition when the dog was walking on the treadmill.

Results

Experiments using bone models resulted in a precision for 3D-bone pose estimation using an uniplanar setup of 0.31 mm for in-plane movements and 4.5 mm for out-of-plane movements. Biplanar data acquisition resulted in a mean root square error of 0.77 mm. Under in-vivo conditions precision of the method may be slightly less, as pose estimation greatly depends on the quality of the fluoroscopic images. Due to

[#]www.xromm.org

overlapping of both stifles during walking and superimposition of the stifle with other anatomical structured such as testes and penis in uncastrated male dogs, contrast of the images may be reduced. Investigation of arthritic stifles is another issue which poses significant problems, as the contours of the bones are less distinct making automatic 2D-3D-image registration challenging.

Conclusion

Fluoroscopic cinematography is a powerful while at the same time minimal-invasive tool to allow for precise estimation of 3D bone kinematics under in-vivo conditions. Our preliminary results in a small number of dogs has changed our understanding of stifle instability, as it appears that in-vivo stifle instability is predominately an unphysiological caudaly directed motion of the femur in relation to the tibia, and not the other way around.

Quantitative analysis of kinematic data in chronic cases of CCL rupture with periarticular fibrosis reveals that even when the stifle appears macroscopically stable significant caudal instability occurs on tow touch. Even though the majority of the CCL deficient stifles experience caudal subluxation of the femur on tow touch, in some cases subluxation already occurs during swing phase and others show a cranio-caudal wobbling at the end of stand phase just before lift of. Regarding TPLO it appears that caudal translation of the femur is limited compared to unoperated dogs. However, whether the femoro-tibial contact patterns of TPLO dogs resemble the one of sound stifles will have to be determined in the future, anticipating significant differences.

References

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