Deep Learning–Based Markerless Motion Tracking as a Cost-Effective Alternative for Large Animal Gait Analysis

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INTRODUCTION: Quantitative gait analysis in large preclinical animal models is an important tool for assessing experimental surgical outcomes and long-term rehabilitation progress. Conventional tools such as marker-based motion capture and instrumented walkways provide accurate kinetic and kinematic data, but are costly, time-intensive, and impractical for routine use – especially in veterinary clinics and farms [1]. Markerless motion tracking enables precise detection of joint trajectories from standard video recordings [2]; however, its reliability and validity in this context remain unproven. The purpose of this study was to evaluate the feasibility of a markerless motion tracking framework for large animal gait analysis. We hypothesized that markerless motion tracking would provide gait measurements that were equally as sensitive to changes in healing as conventional methods (force plate data) while offering improved efficiency and practicality.

METHODS: In an ongoing IACUC-approved study, thirteen adult dogs have been enrolled, including seven with a cranial cruciate ligament (CCL) rupture and reconstruction and 6 controls. This pilot study evaluated one CCL-injured dog within the cohort, which was assessed longitudinally at five time points: (1) pre-operatively, (2) day of surgery, (3) 6 weeks, (4) 8 weeks, and (5) 6 months post-operatively. During each visit, the dog walked across a pressure-sensitive walkway (Tekscan) while being simultaneously recorded in the sagittal plane using a smartphone camera recording at 30 Hz. Kinematic analysis was performed with DeepLabCut™ (DLC), a deep learning-based markerless pose estimation framework. To create a training dataset, 1–2 representative videos were selected, and 80–140 frames were manually labeled with hip, knee, ankle, and toe landmarks. Models were trained using the optimal ResNet-101 architecture for 50,000–100,000 iterations with image augmentation to enhance generalization. Once trained, DLC automatically tracked all joints in the remaining trials and joint angles were derived in MATLAB. To assess gait symmetry, root mean square errors (RMSE) were calculated for the ipsilateral and contralateral joint angles. Separately, symmetry indices were calculated from the walkway kinetic data. The linear correlation between kinetic and kinematic symmetry indices were calculated and one-way ANOVAs with post hoc Tukey's pairwise tests were performed to evaluate differences within groups across time points.

RESULTS: ***Kinematic Analysis:*** At baseline, the dog demonstrated reduced peak knee and ankle flexion compared to later time points (e.g. **Fig. 1A**). Longitudinal tracking revealed progressive recovery following surgery, with knee flexion partially restored by 6–8 weeks and approaching normal patterns by 6 months. RMSE between injured and healthy legs decreased significantly from Visit 1 to Visit 5 for all joints (e.g. **Fig. 1B**). The knee showed the largest reduction, from 21.8± 3.1° at Visit 1 to 5.3 ± 0.9° at Visit 5 ($p<0.0001$). ***Kinetic Analysis:*** Symmetry indices derived from maximum hindlimb forces (ideal score = 0) showed marked asymmetry at baseline, with a normalized score of 29.04 at Visit 1. This asymmetry index progressively decreased following surgery, reaching a mean score of 0.28 at Visit 5 (**Fig. 1C**). ***Correlation between kinematics and kinetics:*** Best-fit linear regression revealed weak-to-moderate associations between RMSE and maximum force symmetry. The hip demonstrated a regression of $R^2 = 0.07$, the knee $R^2 = 0.14$, the ankle $R^2 = 0.17$, and the toe $R^2 = 0.10$ (**Fig. 1D**).

DISCUSSION: This case study demonstrated that markerless motion tracking was sensitive to changes in post-operative rehabilitation. Analysis of joint trajectories showed the joint's angles progressively normalized across visits, with RMSE values decreasing significantly from baseline to 6 months. The most pronounced improvements were observed in the knee, which makes sense, given the nature of the injury. Similarly, pressure-sensing walkways were also able to quantify functional recovery following CCL reconstruction by measuring substantial improvements in limb-loading symmetry. Correlations between RMSE and maximum force symmetry demonstrated that reductions in kinematic variability were paralleled by improvements in kinetic balance, with data clustering tightly by Visit 5. Although the regression fits were not strong, the trend confirmed that joint-level recovery and limb-loading restoration converge over time. Together, these findings demonstrate a relationship between kinematic and kinetic measures for quantitative monitoring of rehabilitation. The implications of a reliable, low-cost analysis of kinematics are substantial. A DLC-based kinematic analysis has potential to not only improve preclinical animal model experiments, but it also provides a new tool in standard veterinary clinics. Limitations of this study include a subject-specific DLC training protocol and evaluation was limited to the sagittal plane. Future work will expand to a larger cohort and explore model generalization for cross-subject use.

SIGNIFICANCE/CLINICAL RELEVANCE: This study shows that reduced kinematic variability (RMSE) aligns with improved limb-loading symmetry, underscoring the sensitivity of markerless motion tracking with low-cost equipment. This scalable, cost-effective approach enables remote, longitudinal monitoring, with significant potential to enhance experimental and clinical assessments of rehabilitation following surgery.

REFERENCES: [1] Gillette+, *Vet. J.*, 2008; [2] Spinella+, *Vet. Sci.*, 2021,

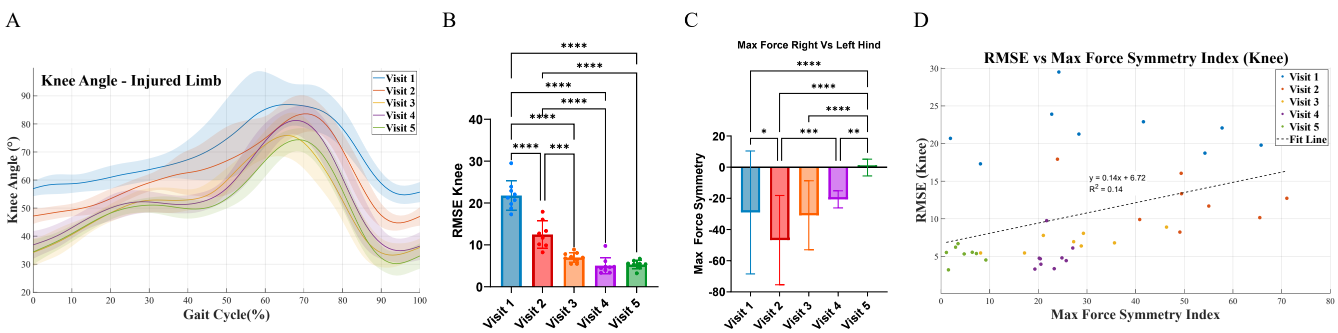

Figure 1*: Quantitative analyses of the knee joint in this pilot study included (A) knee angle trajectories from all strides for the injured limb; (B) RMSE analysis of knee considering injured and contralateral limb; (C) Maximum force symmetry index (right vs. left hind); (D) Correlation between RMSE values and maximum force symmetry index.*