Six Degree of Freedom Range of Motion in Guineafowl

Robert Kambic*, Thomas Roberts*, Stephen Gatesy*
Department of Ecology and Evolutionary Biology, Brown University,
Providence, RI 02912, USA
robert_kambic@brown.edu, thomas_roberts@brown.edu, stephen_gatesy@brown.edu

1 Introduction

The upright, relatively erect hind limbs of ground-dwelling birds have traditionally been considered to use flexion-extension at their hinge-like joints to operate parasagittaly. Yet birds must use additional rotations in order to stand on one leg (both statically and in single support) and to maneuver. What range of motion (RoM) is available at each joint for reconfiguring the hind limb? In other words, what are the passive limits of flexion-extension, abduction-adduction, and internal-external rotation? Are these motions functionally coupled? What fraction of this passive envelope of motion do birds actually employ? Here we present RoM data for the hip, knee, and ankle of a chicken-like bird, the helmeted guineafowl (*Numida meleagris*).

2 Methods

We mapped out the full rotational RoM of three birds using marker-based XROMM [1]. XROMM combines high-speed, biplanar x-ray video with CT-scans of the same individual to create accurate 3-D animations of moving skeletal elements. Following *in vivo* data collection, we removed muscles from the cadaver's hind limb and manipulated segments by hand to record at least 1000 passively limited poses for each joint. Carbide markers surgically implanted into the pelvis, femur, tibiotarsus, and tarsometatarsus were tracked in the calibrated volume to calculate rigid body kinematics and animate polygonal bone models. Explicitly defined joint coordinate systems [2,3] provided six degree of freedom RoM data directly comparable to *in vivo* motion.

3 Results

We visualize the RoM of each joint as a volume in angle-angle-angle space (Fig. 1). Although flexion-extension shows the largest range, substantial long-axis rotation is possible at all three joints. Abduction-adduction is limited at the hip by a secondary articulation (the antitrochanter), but even more restricted at the bicondylar knee and ankle joints (Fig. 2). Significant interactions among rotational degrees of freedom are evident.

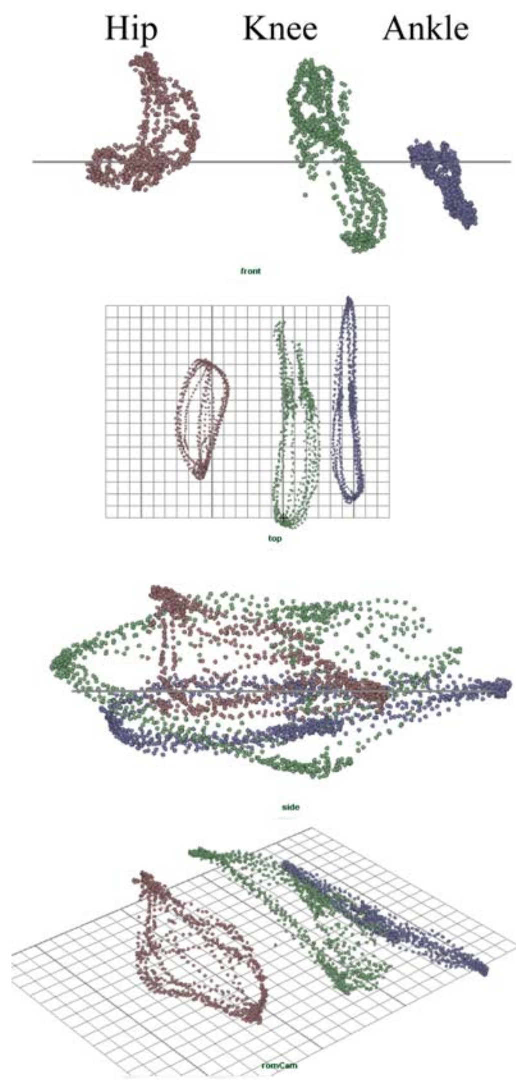

Figure 1: Angle-angle-angle plots of RoM data in four views

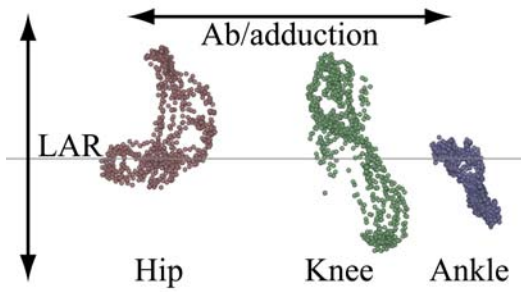

Figure 2: Long axis rotation (LAR) and ab/adduction range of motion at three joints

Plotting *in vivo* angular data within the potential volume reveals that much of the passive envelope for long-axis rotation is used at the hip and knee.

In this system, where the majority of the limb is lateral to the center of mass and abduction-adduction is limited in proximal joints, long axis rotation must coordinate with flexion-extension for foot positioning during steady locomotion and maneuvering.

4 Open Questions

What does range of motion tell us about how a joint is used? Are there situations in which active rather than passive control of a degree of freedom is desirable? What implications does this have for robotic joint design? Are biological joints well-designed systems to be emulated, or compromises among history, constraint, and function?

References

[1] Brainerd, EL., DB. Baier, SM. Gatesy, TL. Hedrick, KA. Metzger, SL. Gilbert, and JJ. Crisco. (2010) X-ray Reconstruction of Moving Morphology (XROMM): precision, accuracy and applications in comparative biomechanics research. Journal of Experimental Zoology, Part A. 313A: 262–279.

[2] Grood, ES., WJ Suntay. (1983) A joint coordinate system for the clinical description of three-dimensional motions: application to the knee.Journal of Biomechanical Engineering. 105(2):136-44.

[3] Wu, G, S. Siegler,P. Allard, C. Kirtley, A. Leardini, D. Rosenbaum, M. Whittle, DD. D'Lima, L. Cristofolini, H. Witte, O. Schmid, I. Stokes. (2002) ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. Journal of Biomechanics. 35(4): 543–548.