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Original Study

Evaluation of Goniometry and Electrogoniometry of Carpus and Elbow Joints in the Barred Owl (*Strix varia*)

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Abstract: The motion of wing joints is a critical factor for successful flight in avian patients, but little information is available about goniometry in birds. Elbow and carpus joints in flexed and extended positions from 10 orthopedically normal wings of 6 adult wild barred owls (*Strix varia*) were evaluated with the animals under general anesthesia using a modified universal plastic goniometer and an electrogoniometer. These measurements were compared to those obtained using radiographic assessment. Intra- and interobserver reliability was calculated. Measurements in live animals were compared to those obtained from frozen-thawed carcasses. Results showed that the modified universal plastic goniometer can be used to obtain accurate results for elbow flexion and extension and for carpal flexion with good to excellent reliability compared to measurements collected from radiographic assessment. Measurements obtained using an electrogoniometer were less accurate and less reliable than those obtained with a plastic goniometer, possibly because of the size and configuration of the model used. Comparison of measurements from live animals and carcasses revealed no significant differences between mean measurements and suggested that further evaluation of carcasses as a model for study of goniometry measurements in avian wing joints should be considered.

Key words: goniometry, electrogoniometry, joint angle, range of motion, avian, barred owl, *Strix varia*

Introduction

Goniometry is the measurement of the range of motion in a joint. It is used frequently in human and veterinary medicine to aid in the diagnosis and management of many musculoskeletal disorders, as well as to monitor the progress of physical therapy and treatment programs. Several clinical methods exist for obtaining goniometric measurements.[1] They include radiographic evaluation, use of a universal plastic goniometer, electrogoniometry, and measurement of joints using physical landmarks in photographs. Studies evaluating goniometry techniques have been performed in dogs, cats, horses, sheep, and alpacas, and demonstrate the potential usefulness of these techniques across a wide variety of species.[2–8]

Injuries affecting bone and soft tissue structures of the wing are common clinical problems encountered by avian veterinarians. Primary damage to ligaments, tendons, muscles, or patagia as well as bone fractures or luxations can lead to abnormal range of motion in associated joints and impaired functionality. Secondary effects related to healing or treatment of wing injuries, such as fibrosis, contracture, callus formation, synostosis, degenerative joint disease, and ankylosis also influence flexion and extension. Primary injuries and secondary effects may contribute to abnormal range of motion in the joints of the wing and can lead to subsequent flight deficits.[9–11] Such injuries are of

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particular concern for avian species or groups that require agile flight for survival in the wild or for sport performance in captive settings.[12,13]

Physical therapy often is recommended to help maintain joint flexibility during recovery from injuries involving the wings,[14] and appropriate range of motion also has been proposed as one criterion for release of avian patients in a wildlife rehabilitation setting.[15] Despite widespread recognition of the importance of range of motion as a critical factor for successful flight in avian patients, very few studies have investigated the use of goniometry measurement in avian species or have established normal reference values.[16,17] We evaluated goniometry measurements obtained using 2 different goniometry methods for elbow and carpus joints in orthopedically normal barred owls (*Strix varia*). The study goals were to: (1) compare measurements obtained using a universal plastic goniometer and an electrogoniometer with those obtained by radiographic assessment, (2) determine the repeatability of the measurements, (3) present descriptive statistics for joint measurements obtained during this study to serve as a species reference, and (4) compare measurements obtained from anesthetized animals to those obtained from frozen-thawed carcasses to determine whether they could serve as a potential model for future goniometry studies in avian species.

Materials and Methods

Animals

Wild barred owls that presented to a wildlife rehabilitation center in North Carolina were selected for enrollment in this study between December 2013 and June 2015. All animals received a veterinary assessment on presentation to the rehabilitation center and treatment with follow-up evaluations for any diagnosed medical conditions. The animals were maintained in individual enclosures or mews and fed diets consisting of frozen-thawed mice. Animals were selected for enrollment in the study if the animal: (1) was of post-fledging age class, (2) had at least 1 uninjured orthopedically normal wing without evidence of previous or ongoing soft-tissue injury as determined by physical examination and orthogonal view radiographs, (3) received a keel score between 2 and 4 of a total score of 5, (4) was a candidate for euthanasia due to circumstances that yielded it nonreleasable to the wild and for which long-term captive placement was unsuitable or unavailable, and (5) was considered to be in a stable medical condition without significant discomfort or could be processed immediately. After enrollment, a procedure to obtain research measurements was performed within 2 days to minimize the length of time in captivity before euthanasia. All animals were monitored daily for pain and distress during this period and continued to receive any necessary medical treatments. Data acquisition was performed using general anesthesia, and all enrolled animals were euthanized at the end of the terminal procedure by methods consistent with current American Veterinary Medical Association euthanasia guidelines. This study and its methodology was approved by the North Carolina Zoo's Research Review Committee.

Study design

Procedure: Each enrolled animal was induced and maintained under general anesthesia with isoflurane gas administered via facemask or endotracheal tube. Animals were monitored throughout the anesthetic procedure by standard techniques, and were maintained at anesthetic depths that allowed complete muscle relaxation for the duration of the procedure. After anesthetic induction, the animal was placed into dorsal recumbency, and a physical examination of the wings was conducted. Goniometric measurements of the elbow and carpus then were obtained for each orthopedically normal and uninjured wing with 3 different methods: (1) using a modified universal plastic goniometer, (2) using an electrogoniometer, and (3) by radiographic assessment. One author (JLG) and 2 volunteer observers first obtained measurements using the plastic goniometer and electrogoniometer methods for each wing. Each observer acquired 3 measurements of each joint in each joint position with both instruments, alternating between flexed and extended positions. The order of assessment using the plastic goniometer and the electrogoniometer was assigned randomly, and all observers were blind to measurements. After goniometric measurements, orthogonal digital radiographs of the wing were acquired. Radiographic measurements were performed on mediolateral views at a later date. Craniocaudal views of the wings also were obtained to fully evaluate the animal for presence of orthopedic or soft-tissue disease. During the procedure, the animal was weighed, received a physical examination, was given a keel score, and was placed into an age class using feather characteristics.[18] All animals were euthanized at the conclusion of the procedure. After euthanasia, masking tape was applied circumferentially to the carcass to maintain the animal's wings in a fixed neutral resting position, and the animal was placed into a plastic bag and stored in a freezer maintained at –18°C for 3 to 14 days. The animal was removed from the freezer and placed into a refrigerator at 4°C for 1 to 3 days to allow complete thawing. Passive range of motion was performed 10 times for each wing evaluated before obtaining postmortem goniometric measurements. Measurements using the universal plastic goniometer and electrogoniometer were repeated by 1 author (JLG) and 2 volunteer observers for each animal as described previously. After completion of postmortem measurements, necropsy was performed to allow sexing of each animal.

Observers: Observers were recruited from a pool of available veterinary students, veterinary technicians, experienced wildlife rehabilitators, and veterinarians with varying levels of experience using goniometry instruments. Each observer was given a tutorial on obtaining goniometry measurements using the two methods before data acquisition. For logistical reasons, the same observers (other than JLG) could not be used throughout the study.

Wing position: Measurements were performed for each goniometry method with the wing in flexed and extended positions. For measurements performed in extension, a restraint device composed of a wooden board and adjustable pegs was used to prevent shifting of the body while the extended wing was placed under traction (Fig 1). Traction was applied to the distal primary feathers to produce full extension perpendicular to the longitudinal body axis and along the coronal plane by using a single strip of masking tape. A spring scale was used to ensure a consistent amount of traction (equivalent to 600 g) during wing extension for all animals. For measurements performed in flexion, observers were instructed to measure the flexed joint position at its 'natural' stopping point (as if the patient had its wing held at rest).

Universal plastic goniometer: To facilitate manipulation during measurements, a clear universal plastic goniometer was modified by cutting each plastic arm to a length of 5 cm and width of 1 cm. The body of the goniometer was covered by an opaque disc of paper to blind the observer to the results, and an assistant was used to record each measurement to the closest degree. For measurement of the elbow, the body of the plastic goniometer was positioned over the joint, and the arms were aligned in a parallel position over the distal diaphysis of the humerus and proximal diaphysis of the ulna to obtain the measurement (Fig 1). For measurement of the carpus, the body of the plastic goniometer was positioned over the joint and the arms were aligned with the distal diaphysis of the ulna and the mid-diaphysis of the major metacarpal bone (Fig 1). Feathers over the joints were moistened with water as needed to facilitate visualization and palpation of the anatomic features, and the joint was flexed and extended as needed by the observer before positioning the joint in the assigned position for measurement.

Electrogoniometer: A twin axis electrogoniometer (SG 110 sensor with ADU 301 angle display unit and J1000 cables; Biometrics Ltd., Ladysmith, VA, USA) composed of 2 rectangular sensor end blocks measuring 54 and 60 mm long and 18 mm wide with a connecting wire approximately 100 mm long between the 2 end blocks was used. The flat attachment surfaces of each end block that are typically affixed to a patient were instead oriented toward the direction of joint angle flexion. Each sensor end block was positioned overlying and parallel with the distal diaphysis of the ulna and the mid-diaphysis of the major metacarpal bone for measurement of the carpus; and overlying and parallel with the distal diaphysis of the humerus and proximal diaphysis of the ulna for measurement of the elbow (Fig 2). As needed by the observer, the end blocks and aligned bone were gripped together by the fingers for flexion and extension of the joint to confirm appropriate positioning before measurement. The instrument was calibrated and tested for accuracy at the beginning of each procedure. To blind the observer to the results, the measurement display unit was only visible to an assistant who recorded the data. Manufacturer specifications for this instrument indicate an accuracy of $\pm$ 2°.[19]

Radiographic assessment: Mediolateral radiographs were obtained for each wing in extended position by using the restraint device and wing traction as described previously. Mediolateral radiographs were obtained in flexion by positioning the wing as if it were at rest followed by abduction at the shoulder joint while maintaining the resting joint angles at the elbow and carpus. Measurements from the digital radiographic images were obtained using computer software for image manipulation and angle measurement (Pixelsticks Version 2.10.1; Plum Amazing, LLC, Princeville, HI, USA). For the elbow joint, lines were drawn as parallel as possible to the bone cortices located at the distal third of the humeral diaphysis and proximal third of the ulnar diaphysis (Figs 3, 4). For the carpus, lines were drawn

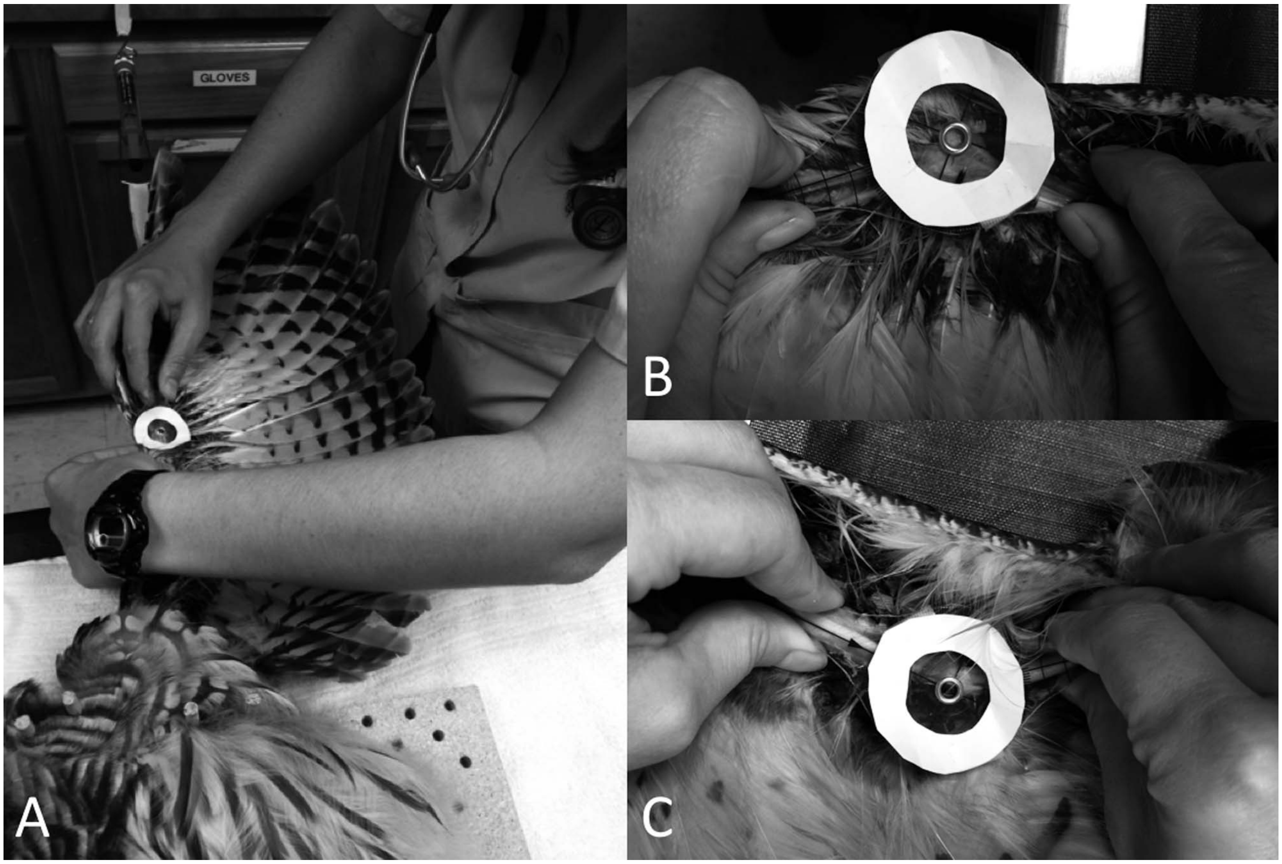

Figure 1. Positioning and techniques used to obtain goniometric measurements for the elbow and carpus joints of a barred owl by using a modified universal plastic goniometer. (A) A restraint device composed of a wooden board and adjustable pegs was used to prevent shifting of the body while the extended wing was placed under traction, and a spring scale was used to ensure a consistent amount of traction was applied to the wing for all animals during wing extension. (B) A modified universal plastic goniometer was used to measure the extended carpus of a right wing (ventral approach) by positioning the body of the plastic goniometer over the joint and aligning the arms of the goniometer so they were overlying and parallel with the distal diaphysis of the ulna and the mid-diaphysis of the major metacarpal bone. The arms of the goniometer and aligned bone were gripped together by the fingers for flexion and extension of the joint to confirm appropriate positioning. (C) A modified universal plastic goniometer was used to measure the extended elbow of a right wing (ventral approach) by aligning the body of the goniometer over the joint and the arms of the goniometer parallel and overlying the distal diaphysis of the humerus and proximal diaphysis of the ulna.

parallel to the bone cortices located at the distal third of the ulnar diaphysis and mid-diaphysis of the major metacarpal bone (Figs 3, 4). The angle produced by the intersection of lines corresponding to the joint of interest was measured and recorded without replication for flexed and extended positions by a single observer (JLG).

Statistical analyses

Descriptive statistics: A mean measurement for each test condition was calculated using 3 repeated measurements from each observer for each test condition. The test conditions included joint type (carpus or elbow), wing position (flexion or extension), and goniometry method used (radiographic assessment, plastic goniometer, or electrogoniometer). Because measurements via radiographic evaluation were obtained by a single observer (JLG) without replication, these measurements were not averaged. Minitab Express (Minitab, Inc, State College, PA, USA) and Excel (Microsoft, Redmond, WA, USA) statistical software were used to derive the descriptive statistical results from mean measurements of all wings evaluated for each test condition.

Comparison of different goniometric methods: Anderson-Darling and Levene's tests were used to evaluate data sets derived from measurements of all observers for normality and equality of

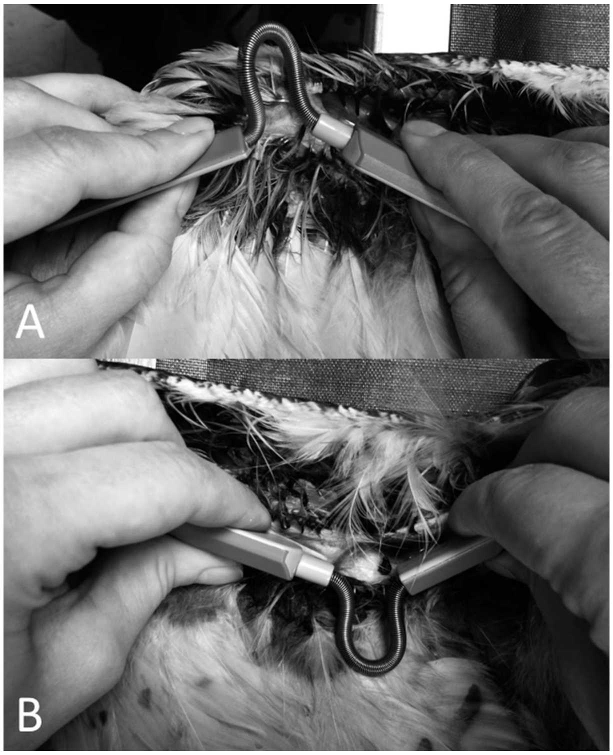

Figure 2. Positioning and techniques used to obtain goniometric measurements for the elbow and carpus joints of a barred owl by using an electrogoniometer. (A) An electrogoniometer was used to measure the extended carpus of a right wing (ventral approach) by positioning each sensor end block overlying and parallel with the distal diaphysis of the ulna and the mid-diaphysis of the major metacarpal bone. The attachment surfaces of the end blocks were positioned to face towards the joint angle being measured. The end blocks and aligned bone were gripped together by the fingers for flexion and extension of the joint to confirm appropriate positioning before measurement. (B) An electrogoniometer was used to measure the extended elbow of a right wing (ventral approach) by aligning each sensor end block overlying and parallel with the distal diaphysis of the humerus and proximal diaphysis of the ulna.

variances for each test condition. Because some data sets had nonnormal distribution or differences in variances, the Mann-Whitney *U* test was used to compare measurements obtained with the different goniometry methods. Significance for all tests was set at $P < .05$. Minitab Express statistical software was used for this analysis. Bland-Altman plots of goniometry measurements made by all observers with radiographic assessment and those obtained using a universal plastic goniometer were created using Excel statistical software to further evaluate the different methods of measurements.

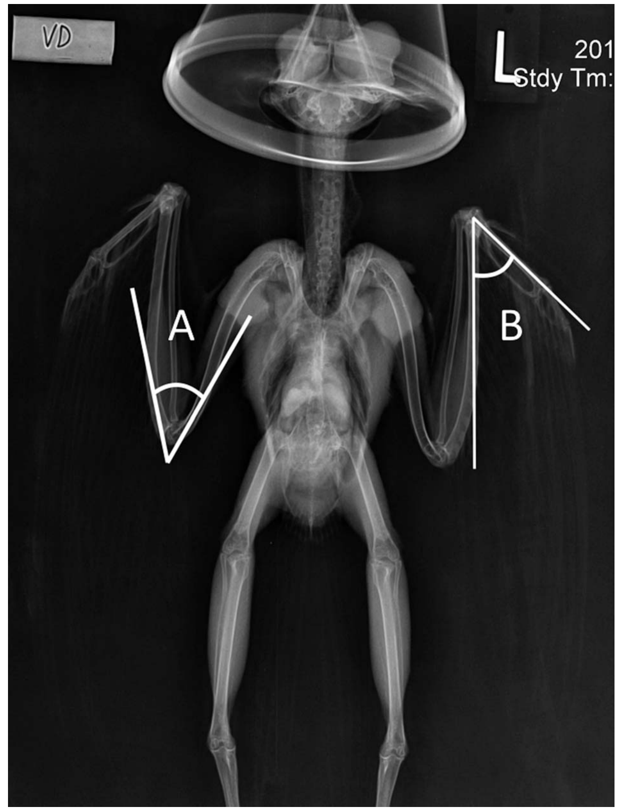

Figure 3. Goniometry measurements for the flexed elbow and carpus joints of a barred owl using radiographic assessment. For the elbow, lines were drawn as parallel as possible to the bone cortices located at the distal third of the humeral diaphysis and proximal third of the ulnar diaphysis (A). For the carpus, lines were drawn parallel to the bone cortices located at the distal third of the ulnar diaphysis and mid-diaphysis of the major metacarpal bone (B). The angles produced by the intersection of lines for the joint of interest were measured.

Intraclass correlation is used frequently in sports medicine to evaluate the reliability of goniometry measurements, and it assesses correlation and agreement.[20–22] Although there is no agreed upon standard interpretation for intraclass correlation coefficients (ICC), values < 0.5 were considered poor, 0.5 to 0.75 moderate, 0.75 to 0.9 good, and $>$ 0.9 excellent throughout this study.[20] To further evaluate and compare the different goniometry methods, measurements obtained by a single observer (JLG) were used to calculate an ICC for reliability between measurements made using the three different goniometric methods. All repeated measurements obtained by this observer for each test condition were averaged. Because only single measurements without replication were obtained using radiographic evaluation, these measurements

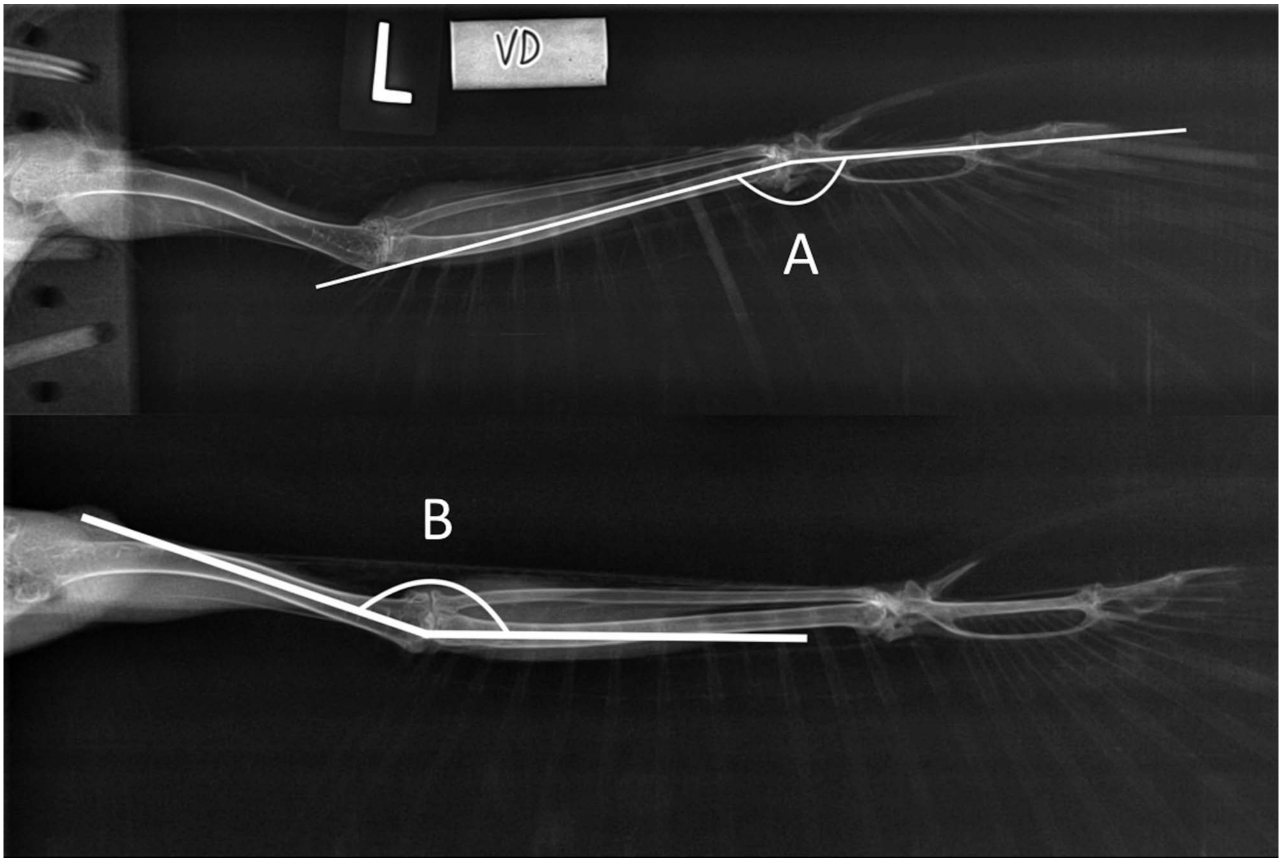

Figure 4. Goniometry measurements for the extended carpus and elbow joints of a barred owl using radiographic assessment. For the carpus, lines were drawn parallel to the bone cortices located at the distal third of the ulnar diaphysis and mid-diaphysis of the major metacarpal bone (A). For the elbow, lines were drawn as parallel as possible to the bone cortices located at the distal third of the humeral diaphysis and proximal third of the ulnar diaphysis (B). The angles produced by the intersection of lines for the joint of interest were measured.

were not averaged. A 2-way mixed effects ICC (3,k) for consistency was calculated between measurements obtained using each goniometry method. SPSS statistical software (IBM Corp, Armonk, New York, USA) was used to calculate all ICCs.

Repeatability of goniometric methods: Intraclass correlation coefficients also were calculated to evaluate intraobserver and interobserver reliability of goniometry measurements obtained using the modified universal plastic goniometer and electrogoniometer. To evaluate intraobserver reliability, 3 single repeated measurements made by one representative observer (JLG) were compared for each testing condition. An ICC (3,1) for consistency was calculated using a 2-way mixed effects model between the 3 single repeated measurements with the human observer considered a fixed effect. To evaluate interobserver reliability, a mean measurement from 3 single repeated measurements for each of 3 separate observers was compared for each testing condition. An ICC (1,k) for consistency was calculated using a 1-way random effects model. Because human observers were not consistent across all wings evaluated, the human observer was considered a random effect.

Comparison and reliability of ante- versus postmortem measurements: Mean of repeated measurements obtained ante- and postmortem after frozen storage by one observer (JLG) were used for statistical analyses. Anderson-Darling and Levene's tests were used to evaluate the data for normal distribution and for equal variances. A significance level of $P < .05$ was used for both tests. Because all data sets were considered to have normal distributions and similar variances, a Student's *t*-test was used to compare ante- and postmortem measurements for each test condition. Significance level was set at $P < .05$. Intraclass correlation coefficients also were calculated for each test condition between measurements made

Table 1. Mean goniometry measurements of carpus and elbow joints in flexed and extended positions measured by 3 different methods in adult wild barred owls.

Joint and position	*n*	Mean ± SD, degrees			95% CI, degrees		
		Rad	Plastic	Electro	Rad	Plastic	Electro
Observers (observations[a])		1 (1)	3 (3)	3 (3)			
Carpus							
Flexed	10	45 ± 4	47 ± 6	67 ± 17[b]	43 - 47	43 - 50	57 - 78
Extended	9	174 ± 3	169 ± 4[b]	163 ± 6[b]	172 - 176	166 - 171	159 - 166
Elbow							
Flexed	10	38 ± 4	39 ± 8	54 ± 12[b]	35 - 41	35 - 44	47 - 62
Extended	9	157 ± 3	152 ± 7	147 ± 10	155 - 159	148 - 156	141 - 153

Abbreviations: CI, confidence interval; Electro, electrogoniometer; Plastic, universal plastic goniometer; Rad, radiographic assessment; SD, standard deviation.

[a] Number of observations obtained by each observer.

[b] Results significantly different compared to results of radiographic assessment ($p < .05$).

ante- and postmortem using a 2-way random effects ICC (2,k) model for consistency.

Results

Animals

Ten wings from 6 birds (3 male and 3 female) were enrolled in the study. All birds were of after-hatch-year age class with a mean (± SD) weight of 0.69 ± 0.10 kg (range, 0.53–0.74) and mean keel score of 2.7 ± 0.4 of 5. All wings evaluated were determined to be orthopedically normal by physical examination and radiographic evaluation. Mean duration of freezer storage for carcasses was 8.9 ± 3.1 days (range, 4.7–13.0). Mean thawing time in a refrigerator for the carcasses was 2.3 ± 0.7 days (range, 1.3–3.1).

Goniometry measurements

Goniometry measurements of barred owls: Mean, standard deviation, and 95% confidence interval for goniometric measurements obtained using the 3 different measurement methods from all observers for each joint and joint position are presented in Table 1. Standard boxplots of this data depicting the median, minimum, maximum, and interquartile range for the 3 goniometric measurement methods in each joint and joint position are depicted in Figure 5.

Comparison of different goniometry methods: Results of the Mann-Whitney *U* test for comparisons between measurements obtained using the 3 different goniometric methods for all observers are depicted in Table 1 and Figure 5. Measurements using the electrogoniometer for the carpus joint in both positions and the elbow joint in the flexed position were significantly different from those obtained using radiographic assessment. For the universal plastic goniometer, only measurements of the extended carpus were statistically different from those obtained using radiographic assessment, and measurements for the elbow joint in both positions and the carpus in a flexed position were not statistically different from measurements obtained using radiographic assessment. Bland-Altman plots of mean goniometry measurements for all observers using radiographic assessment and those obtained using a universal plastic goniometer or an electrogoniometer are depicted in Figure 6. The limits of agreement for the universal plastic and electrogoniometer were 15° and –12° (mean difference of 1°) and 32° and –43° (mean difference of –5°), respectively. Both methods tended to underestimate flexed and overestimate extended joint measurements compared to radiographic assessment.

Results of ICCs for comparison of measurements made by one observer using the 3 different goniometry methods are depicted in Table 2. Intraclass correlation coefficients were considered excellent for measurements made by the universal plastic and electrogoniometers when compared to those obtained with radiographic assessment for the carpus (0.958–0.997), elbow (0.966–0.996), and all joints (0.962–0.997). When only flexed joints were compared, reliability was considered good (0.769) for the plastic goniometer and poor (0.204) for the electrogoniometer. When only extended joints were compared, reliability was considered good (0.890) and moderate (0.713), respectively. Regardless of joint or position, reliability for measurements using the plastic goniometer was higher than that for the electrogoniometer when compared to measurements obtained using radiographic assessment.

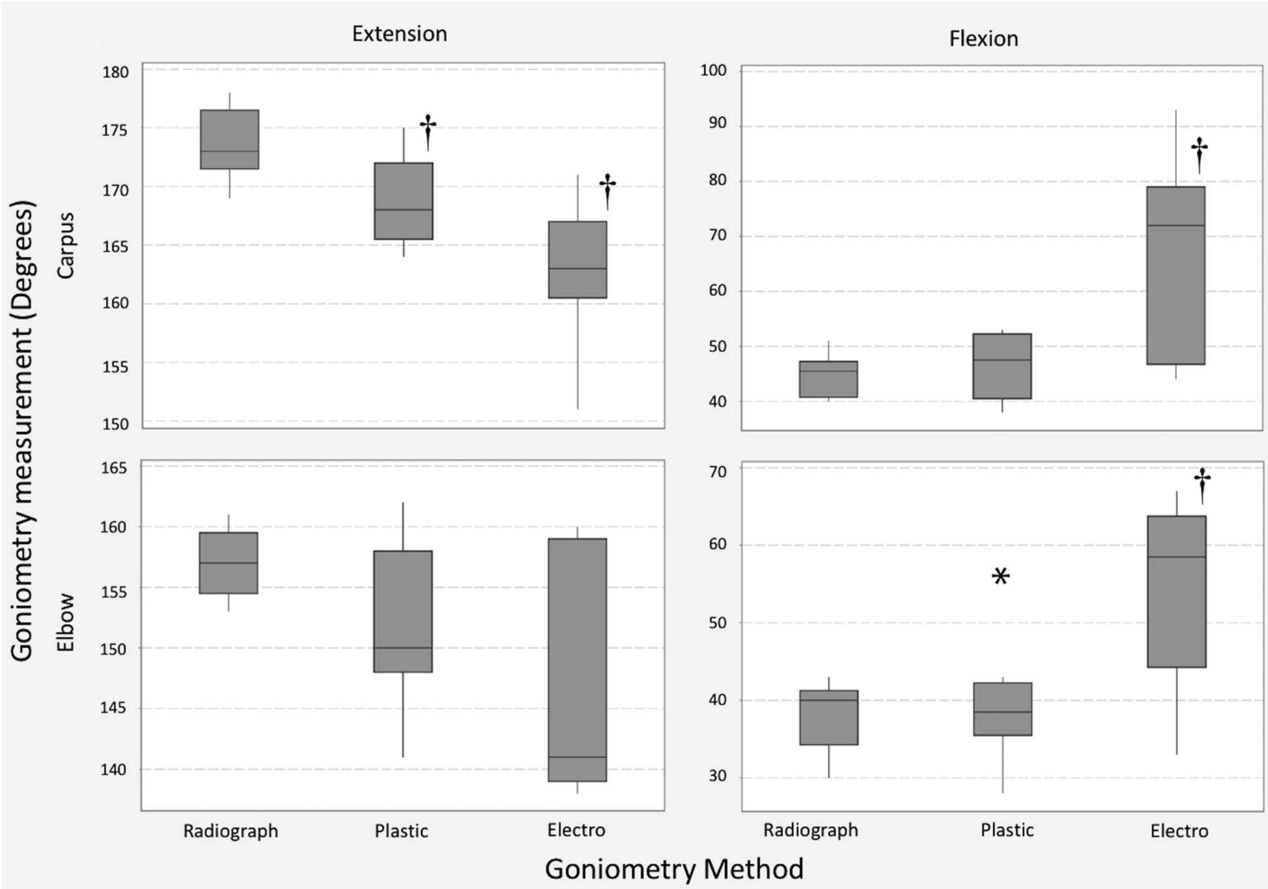

Figure 5. Boxplots of goniometry measurements obtained using radiographic assessment (Radiograph), a universal plastic goniometer (Plastic), and an electrogoniometer (Electro) in adult wild barred owls. Outliers are indicated by asterisks (*). Statistical differences between methods are indicated by an obelus (†).

Repeatability of goniometric methods: The ICC values for intra- and interobserver reliability are presented in Table 3. Intraclass correlation coefficients for intraobserver reliability, between individual measurements made by the same observer for the carpus, elbow, and all joints by the modified plastic and electrogoniometers were indicative of excellent reliability and ranged from 0.949 to 0.995. When evaluating reliability of measurements for extended joints, the ICC value was excellent (0.917) for those made with the plastic goniometer but only moderate for those made by electrogoniometry (0.712). For flexed joint measurements, the ICC was moderate (range, 0.632–0.666) for both methods. The intraobserver reliability was higher for the plastic than for the electrogoniometer for all measurements of extension.

Intraclass correlation coefficients for interobserver reliability, between the same measurement made by three separate observers indicated excellent reliability and ranged from 0.983 to 0.995 for the carpus, elbow, and all joints for both goniometry methods. When evaluating reliability of measurements for extended joints, the ICC value was excellent (0.922) for those made with the plastic goniometer, but only good for those made by the electrogoniometer (0.792). For flexed joint measurements, the ICC was only moderate for the plastic goniometer (0.550) but indicated good reliability (0.835) for measurements made with the electrogoniometer. Measurements made using the plastic goniometer had higher interobserver reliability than those obtained by the electrogoniometer for all measurements of extension.

Comparison and reliability of ante- and postmortem measurements: Significant differences were not identified by Student *t*-tests between mean measurements made ante- and postmortem with the universal plastic or electrogoniometer for any test condition (Fig 7). Intraclass correlation coefficients between ante- and postmortem measurements were excellent for the elbow (0.975–0.998), carpus (0.962–0.998), and all joints (0.998)

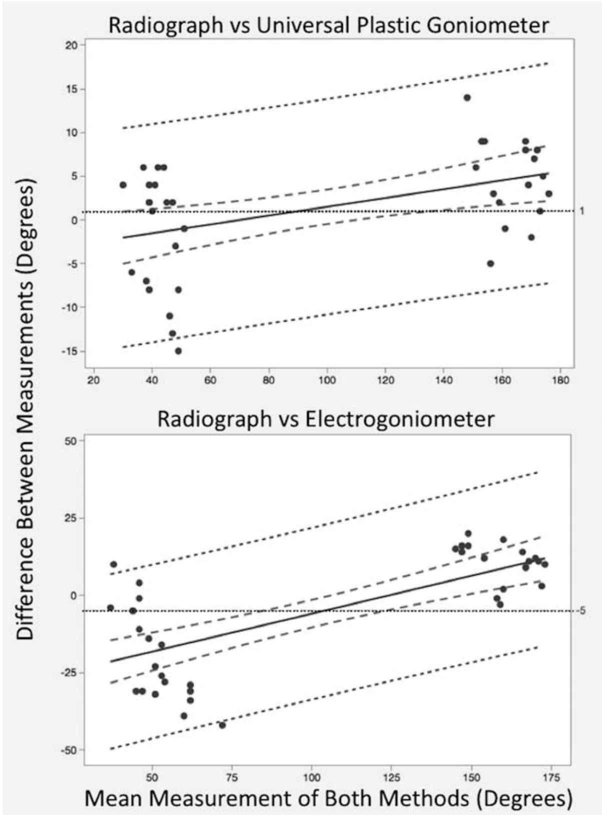

Figure 6. Bland-Altman plots of goniometry measurements made by radiographic assessment and those obtained using a universal plastic goniometer or an electrogoniometer in adult wild barred owls. Regression lines (*solid line*) with 95% confidence intervals (*long-dashed lines*), mean differences (*dotted line*), and prediction limits (*short-dashed lines*) are indicated for each plot.

for both goniometry methods (Table 4). When evaluating reliability of measurements for extended joints, the ICC value was excellent (90.963) the plastic goniometer measurements, but only moderate for the electrogoniometer (0.575). When evaluating reliability of measurements for flexed joints, the ICC value was good for the universal plastic goniometer (0.847), but only moderate for the electrogoniometer (0.748). Regardless of joint or position, reliability for measurements using the plastic goniometer was higher than that for electrogoniometric measurements.

Discussion

We evaluated the use of a universal plastic goniometer and an electrogoniometer for obtaining joint angle measurements of the carpus and elbow in wild adult barred owls using measurements made by radiographic assessment as a gold standard for comparison. Our results indicated that the modified universal plastic goniometer can be used to obtain accurate results for the elbow in flexed and extended positions and for the flexed carpus with good to excellent reliability. For most joints and positions evaluated, the electrogoniometer had poor accuracy and was less reliable than the modified universal plastic goniometer. These results suggested that, compared to radiographic assessment, a modified universal plastic goniometer may be the preferred method over the electrogoniometer used in this study for obtaining goniometric measurements in wing joints.

Use of universal plastic goniometry to measure joint angles is an accurate and reliable method in human and veterinary patients for select joints,[2–7,23,24] and our results showed that this method with slight modification also can be used to obtain accurate and reliable results in select wing joints for an avian species. Although electrogoniometry has been found to be an accurate and reliable method for obtaining joint angle measurements in humans and some veterinary species,[6,25,26] this method of measurement cannot be recommended for use in avian wing joints based on the results of our investigation. The electrogoniometer used in this study converts bending strain of the connecting wire into proportional electrical signals, which are used to determine the angle between the 2 sensor end blocks.[19] The connecting wire between the 2 sensor end blocks was longer than may be ideal for the joints of interest in our study, and positioning of the sensor heads by observers for appropriate alignment with the anatomic landmarks for the joints frequently caused buckling of the connecting wire during measurement. This could have altered

Table 2. Reliability between measurements obtained using 2 different goniometry measurement methods and those obtained with radiographic assessment by a single observer in adult wild barred owls.

		ICC[a]	
Joint	*n*	Rad[b] vs plastic	Rad[b] vs electro
Carpus	19	0.997	0.958
Elbow	19	0.996	0.966
Flexed	20	0.769	0.204
Extended	18	0.890	0.713
All joints	38	0.997	0.962

Abbreviations: Rad, radiographic assessment; Plastic, universal plastic goniometer; Electro, electrogoniometer.
[a] Intraclass correlation coefficients were calculated with a 2-way mixed effects model (3,k) for consistency using mean measurements.
[b] Radiographic measurements represent single measurements.

Table 3. Intra- and interobserver reliability of measurements obtained using a modified universal plastic goniometer and an electrogoniometer for elbow and carpus joints of adult wild barred owls.

		ICC			
		Intraobserver[a]		Interobserver[b]	
Joint	*n*	Plastic	Electro	Plastic	Electro
Carpus	10	0.995	0.970	0.995	0.983
Elbow	10	0.992	0.949	0.995	0.983
Flexed joints	20	0.632	0.666	0.550	0.835
Extended joints	20	0.917	0.712	0.922	0.792
All joints	40	0.994	0.959	0.995	0.983

Abbreviations: Plastic, universal plastic goniometer; Electro, electrogoniometer; ICC, Intraclass correlation coefficient.

[a] Two-way mixed effects ICC model (3,1) for consistency between 3 single repeated measures obtained by a single observer.

[b] One-way random effects ICC model (1,k) for consistency between mean measurements obtained by 3 different observers.

Table 4. Reliability between goniometry measurements obtained antemortem under anesthesia and measurements obtained postmortem after frozen storage in adult wild barred owls (*Strix varia*) obtained by a single observer.

		ICC[a]	
Joint	*n*	Universal plastic goniometry	Electrogoniometry
Carpus	19	0.998	0.962
Elbow	19	0.998	0.975
Flexed joints	20	0.847	0.748
Extended joints	18	0.963	0.575
All joints	38	0.998	0.968

[a] Two-way random effects ICC model (2,k) for consistency between mean measurements collected by a single observer.

the bending strain of the wire with subsequent effects on measurement accuracy. Additionally, because of the small anatomy and specific conformation of the avian joints of interest in this study,

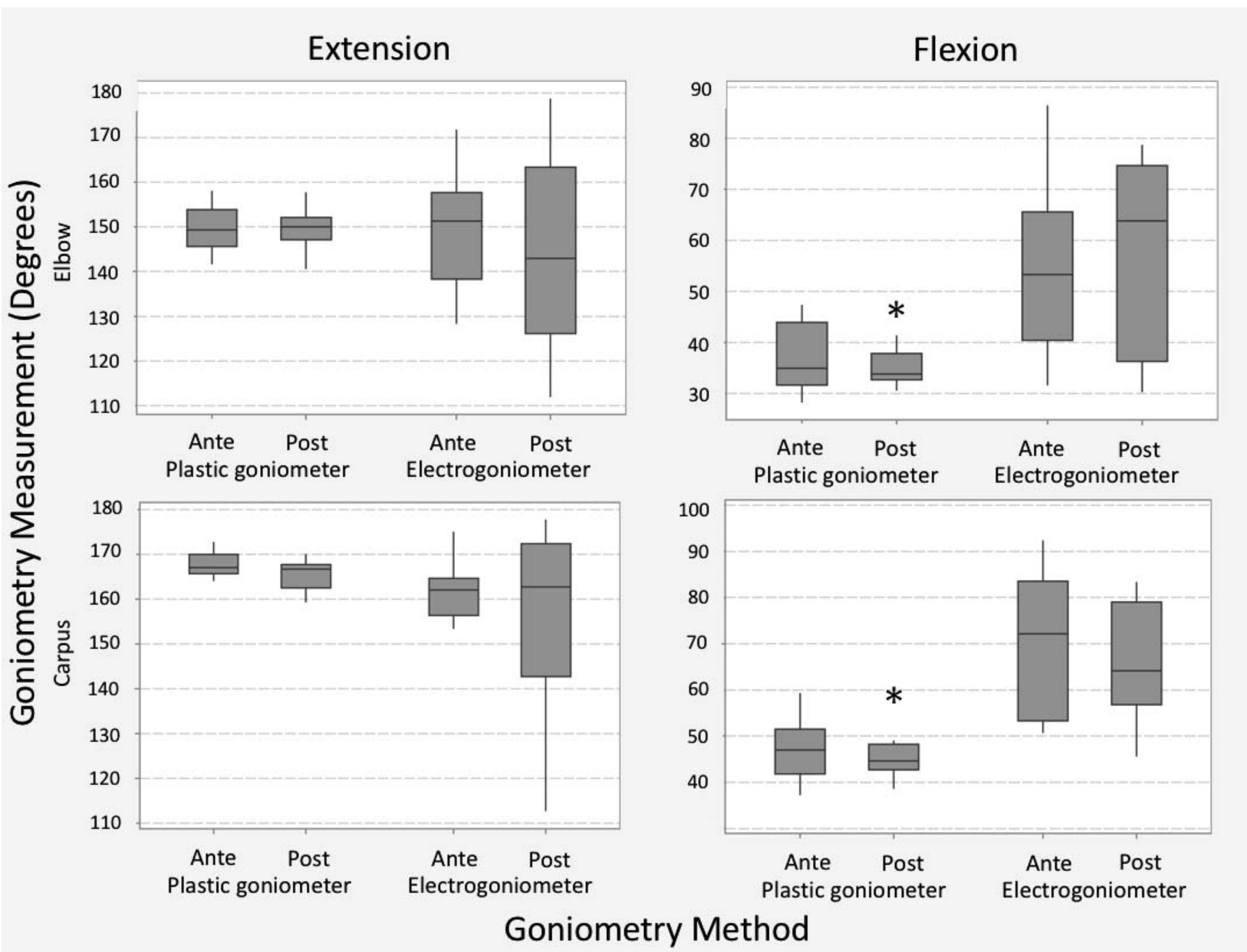

Figure 7. Boxplots of goniometry measurements obtained in live barred owls antemortem under general anesthesia (ante) and postmortem on carcasses after freezing and thawing (post). Outliers are indicated by asterisks (∗).

affixation of the electrogoniometer to the joint as performed in humans was not feasible, and manual application and alignment of the electrogoniometer was used instead. The bulkier sensor heads may have been less ergonomic for observers to use than the modified universal plastic goniometer, and this also could have introduced additional variation in the application of the instrument to the joint during measurement. Possibly, an electrogoniometer with smaller sensor heads and a shorter and more flexible connecting wire than the model used in our study could yield more accurate and reliable results.

Differences in reliability between measurements made in flexed positions compared to those made in extended positions were notable. Intra- and interobserver reliability were only moderate for flexed joints compared to excellent for extended joints. Anecdotally, many avian wing joints can be easily hyperextended and hyperflexed past the point of normal passive range of motion with manual manipulation. Inclusion of hyperextended and hyperflexed measurements was avoided in this study by designing methodology to target measurements of passive range of motion rather than maximal range of motion in the joints of interest. This was achieved for extended measurements by placing each wing under consistent traction during measurement and by instructing observers to measure joint angles at their 'natural' stopping point (as if the wing was held at rest) for flexed measurements. The method used for establishing a consistent extended wing position yielded very reliable results. The method used for establishing a consistent flexed wing position was less objective and less controlled and likely contributed to the lower reliability in measurements of flexed joints. Wing extension, and, hence, the reliability of goniometry measurements made in this position, possibly have more practical clinical value in predicting flight ability than measurements of wing flexion. If true, this could mitigate the importance of lower reliability in flexed joint measurements but would require further investigation to determine.

Use of frozen-thawed carcasses as a model to establish normal goniometry measurement reference ranges is an appealing prospect because of logistical and cost advantages over performing such studies in live animals. The potential effects of rigor mortis, decomposition, and the effects of freezing and thawing on goniometry measurements prohibited use of avian carcasses as a model for this study, and, thus, a limited evaluation of carcasses as a model for live animals was included in this investigation. No significant differences were found in mean measurements of joints in live versus deceased animals for both methods used, and measurements made with the modified universal plastic goniometer in live and deceased animals had good to excellent reliability. These results suggested that further evaluation of carcasses as a model for the study of goniometry measurements in avian wing joints should be considered.

While our results have practical application for performing goniometry in avian species, they should be interpreted carefully. The wings (n = 10) evaluated in this study were from a small number of birds (n = 6) and may not be representative of the larger population of barred owls. The small sample size also limited the scope and power of the statistical analyses. Additionally, because of small sample sizes, evaluation for differences in measurements due to factors, such as sex, time in captivity, left or right wing, disease status, keel score, and other factors could not be performed and would benefit from further investigation. Extrapolation of our results to other bird species should be done cautiously because of the large variation that exists between species with regards to body size, bone shape, joint orientation, tendon flexibility, and other factors that could make extrapolation inappropriate. Furthermore, this study used measurements made by radiographic assessment as the basis of comparison. For logistical reasons, measurements obtained by radiographic assessment were unreplicated and obtained by a single observer; thus, the repeatability of these measurements is unknown. Radiographic measurements frequently are considered the gold standard for comparison in humans and other species for a variety of joints,[1,3,5,7,23,24] and were assumed to be the gold standard for comparison in avian species as well. However, this could be a false assumption for avian patients and warrants further directed study.

Our results indicated that, compared to measurements made by radiographic assessment, the modified universal plastic goniometer can be used to obtain accurate results for the elbow in flexed and extended positions and for the flexed carpus with good to excellent reliability in adult wild barred owls. Because of overall better accuracy and reliability, this method may be preferred over electrogoniometry with the unit model used in this study. The goniometry measurements obtained in this study can be used as a reference for this species. Comparison of measurements obtained antemortem to those obtained from carcasses after frozen storage show promise for the use of carcasses as a model for live animals in future goniometry studies and warrants further investigation.

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