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Original Study

Radiographic Cardiac Silhouette Evaluation of Healthy Texas A&M White Quail (*Coturnix* sp.)

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Abstract: The aim of this study was to determine reference values for the width and length of the heart of Texas A&M white quail (*Coturnix* genotype; meat-type white quail) in relation to other anatomic landmarks. The cardiac silhouettes of 24 Texas A&M white quail were measured in ventrodorsal and right laterolateral projections using radiographic images without sedation. Cardiac width, thoracic width, coracoid width, distance between the third and fourth ribs, synsacrum width, and distance between clavicles were evaluated on ventrodorsal radiographic images. The widest point of the heart, length of the heart from the height of the aorta and pulmonary artery to the apex, length of the sternum from the insertion of the coracoid to the caudal edge, and depth of the sternum (90° from the junction of the coracoid to the sternum) were analyzed on the right lateral radiographic images. The mean ± SD cardiac width in the 24 Texas A&M white quail was 13.44 ± 1.99 mm with lower and upper limits of 10.1 mm and 18.41 mm, respectively. The results showed a strongly significant correlation between the ratio of cardiac width/thoracic width ($P < 0.001$) and cardiac width/coracoid width ($P = 0.003$). The radiographic reference intervals calculated in this study, especially thoracic widths, can be used in the evaluation process of cardiac size in quail.

Key words: cardiac measurements, radiography, reference values, avian, Texas A&M white quail

INTRODUCTION

Radiographic imaging and measurement of the cardiac silhouette is a frequently used method of examination in avian species[1,2] and can be used to help detect cardiac pathologies. Cardiac reference values have been used as prognostic indicators of mitral diseases in dogs and for determination of cardiac enlargement in cats and avian species.[3–7] Radiographic assessment of cardiac enlargement in birds is an important adjunct to physical examination because many birds' high heart rates make it challenging to physically evaluate them for murmurs or arrhythmias.[7–10] Additional cardiac diagnostic techniques, such as angiography, electrocardiography, echocardiography, and computed tomography, can also be performed.[8,11]

To interpret radiographic images, it is necessary to know the size and position of internal organs in healthy animals.[12] Radiographic interpretation is based on the evaluation of the size and shape of the organ silhouettes and the knowledge of the veterinarian assessing them. Reference values for heart silhouette measurements with or without the use of anesthesia should be established for each species because the ratio of heart size to body size varies considerably between different species.[8,13] Many studies have established reference values of the cardiac silhouette in different domestic and wild birds, including ospreys (*Pandion haliaetus*), common kestrels (*Falco tinnunculus*), galahs (*Eolophus roseicapilla*), screech owls (*Otus asio*), red-tailed hawks (*Buteo jamaicensis*), Canada geese (*Branta canadensis*), grey parrots (*Psittacus erithacus*), Senegal parrots (*Poicephalus senegalis*), orange-winged Amazon parrots (*Amazona amazonica*), peregrine falcons (*Falco peregrinus*), budgerigars (*Melopsittacus undulatus*), Spix's macaws (*Cyanopsitta spixii*), Humboldt penguins (*Spheniscus humboldti*), Harris' hawks (*Parabuteo unicinctus*), saker falcons (*Falco cherrug*), lanner falcons (*Falco biarmicus*), blue-fronted Amazon parrots (*Amazona aestiva*), bald eagles (*Haliaeetus leucocephalus*), Bonelli's eagles (*Aquila fasciata*), common mynahs (*Acridotheres tristis*), and white storks (*Ciconia ciconia*);[6–9,12,14–25] however, to the best of the authors' knowledge, no study has measured the cardiac silhouette of Texas A&M white quail (*Coturnix* genotype; meat-type white quail). The Texas A&M white quail has been selectively bred for meat production at Texas A&M

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University (College Station, TX, USA).[26] This study was performed to establish radiographic reference values for the cardiac silhouettes of Texas A&M white quail.

MATERIALS AND METHODS

This study was approved by the Aydin Adnan Menderes University Animal Experiments Local Ethics Committee (#64583101/2023/54). Twenty-four 10-week-old Texas A&M white quail (12 females, 12 males) ranging in body weight from 370 to 435 g were obtained from the Aydin Adnan Menderes University, Faculty of Veterinary Medicine, Poultry Research and Practice Unit for this study. The quail were kept in 5 × 44 × 30 cm cages with 50%–60% relative humidity, heaters (22 ± 1°C [71.6°F]), feeders, and water sources. Each cage housed up to 3 adult quail: 2 females, 1 male. All quail were fed a balanced diet based on life stage and the diets were formulated to meet the Nutritional Research Council requirements.[27] Water was provided ad libitum. All quail underwent physical examinations before the study and were deemed clinically healthy with no signs of physical abnormalities.

Radiographs were performed in ventrodorsal (VD) and right lateral positions under manual restraint using a mobile radiographic device and Bucky table (150 Kv, 500 mAS; Comed Medical Systems Co, Seongnam, Gyeonggi-do, South Korea) and CR system (ImagePilot Sigma, Konica Minolta Healthcare Americas, Inc, Wayne, NJ, USA).

All radiographic measurements were obtained 3 times by 3 different observers to limit bias, and their average values were recorded. For the VD view, the quail were positioned in dorsal recumbency with their wings and legs extended laterally and caudally, respectively. Six measurements were collected from the VD radiographs: cardiac width (CW), cranial coelom/thoracic width (TW), coracoid width (CoW), distance between the third and fourth ribs (RD), synsacral width (SW), and the distance between the clavicles (ClD; Fig 1A). For the right lateral view, the wings were extended dorsally and positioned symmetrically with 1 overlapping the other, and the legs were extended caudally. Right lateral measurements were made at the widest point of the heart (HW), length of the heart (HL, height from the aorta and pulmonary artery to the apex), length of the sternum (SL, from the insertion of the coracoid to the caudal edge), and depth of the sternum (SC, 90° from the junction of the coracoid to the sternum; Fig 1B).

Statistical analysis

The variables analyzed were the CW, SC, TW, CoW, CID, SW, and RD and the ratios between the CW and each of the other 5 anatomic structures. The anatomical indices were investigated using the Shapiro-Wilk test to

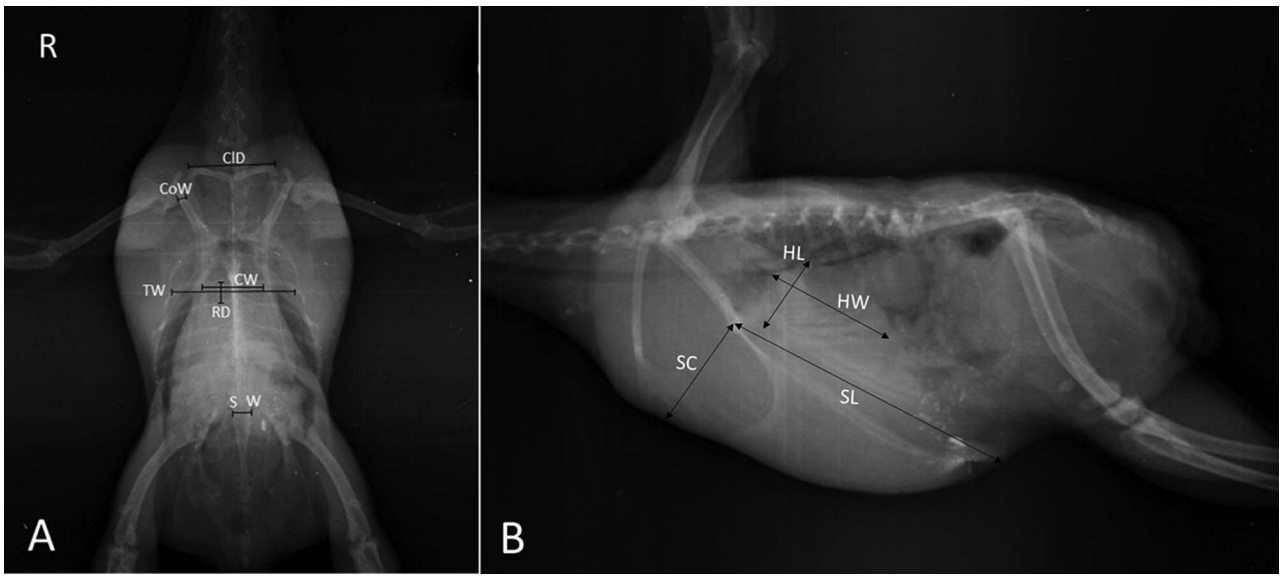

Figure 1. (A) Ventrodorsal (VD) measurements in a radiograph: thoracic width (TW), cardiac width (CW), distance between third and fourth ribs (RD), clavicular distance (ClD), coracoid width (CoW), and synsacrum width (SW) of Texas A&M white quail (*Coturnix* genotype; meat-type white quail). (B) Right lateral (RL) measurements in a radiograph: widest point of the heart (HW); length of the heart at height of the aorta and pulmonary artery to the apex (HL), length of the sternum from the insertion of the coracoid to the caudal edge (SL), depth of the sternum 90° from the junction of the coracoid to the sternum (SC) of Texas A&M white quail (*Coturnix* genotype; meat-type white quail).

Table 1. Descriptive statistics for cardiac size and other anatomical indices obtained from ventrodorsal radiographs in Texas A&M white quail (*Coturnix* genotype; meat-type white quail; n = 24).

					95% Reference interval	
Variable, mm	Mean ± SD	Min–Max	CV, %	Median	Lower limit (90% CI)	Upper limit (90% CI)
CW	19.36 ± 2.91	13.94–25.94	15.1	19.51	18.34 (17.75–18.93)	20.38 (19.79–20.97)
TW	35.10 ± 3.10	29.50–44.30	8.8	34.80	34.02 (33.39–34.65)	36.19 (35.56–36.82)
CoW	2.58 ± 0.51	1.76–4.32	19.6	2.52	2.40 (2.30–2.50)	2.75 (2.65–2.85)
ClD	20.75 ± 2.44	15.89–28.20	11.8	20.22	19.89 (19.39–20.39)	21.60 (21.10–22.10)
SW	4.58 ± 0.53	3.56–5.65	11.6	4.61	4.40 (4.29–4.51)	4.80 (4.69–4.91)
RD[a]	6.25 ± 0.43	5.64–7.35	6.9	6.19	6.09 (6.00–6.18)	6.40 (6.31–6.49)

Abbreviations: CW, cardiac width; TW, thoracic width; CoW, coracoid width; ClD, clavicular distance; SW, synsacrum width; RD, rib distance; SD, standard deviation; Min, minimum; Max, maximum; CV, coefficient of variation; CI, confidence interval.

[a] Distance between third and fourth ribs.

determine whether they were normally distributed. As both parameters were normally distributed, the correlation coefficients and their significance were calculated using the Pearson correlation test. The correlations were also tested separately for the CW and VD radiographic measurements and among lateral radiographic measurements. A 5% type-I error level was used to infer statistical significance.[28] Ninety percent reference intervals were calculated for the different measurements using the robust approach. After controlling for body weight, a linear regression model was used to evaluate the correlation between CW and other VD radiographic indices, including TW, CoW, CID, SW, and RD. To select the explanatory variables that best described CoW, a backward stepwise approach was used. Variables not significantly correlated with CW were removed from the model until the estimated regression coefficients for the retained variables were statistically significant ($P < 0.05$). Commercial statistical software (SPSS Version 22.0, IBM Corp, Armonk, NY, USA) was used to analyze the data.

RESULTS

The mean ± SD and 95% reference intervals for the VD radiographic indices CW, TW, CoW, ClD, synsacrum, and RD are listed in Table 1. The mean ± SD of CW was 19.36 ± 2.91 mm with lower and upper limits of 18.34 mm and 20.38 mm, respectively.

Measurements made from right lateral radiographs for HW, HL, SL, and SC are listed in Table 2. The mean ± SD of CW was 13.44 ± 1.99 mm with lower and upper limits of 10.1 mm and 18.41 mm, respectively. The ratios of CW to other anatomic indices are listed in Table 3, and Pearson correlation coefficients are provided in Table 4. Significant positive correlations were identified between CW:TW ($r = 0.744$, $P < 0.001$) and CW:CID ratios ($r = 0.539$, $P = 0.003$).

A significant relationship was identified between CW and TW ($R^2 = 0.55$, $P < 0.001$). A linear regression formula between CW and TW found: TW (mm) = 19.78 + (0.79 × CW [mm]) (Fig 2A). A significant positive relationship was also found between ClD and CW using the following formula: ClD (mm) = 11.99 – (0.45 × CW [(mm]) (Fig 2B).

Other anatomic indices demonstrated no significant association with CW. Table 5 presents Pearson correlation coefficient (r) and correlation significance from right lateral radiographic measurements. A significant positive correlation ($r = 0.609$, $P = 0.002$) was detected between HW and HL.

Table 2. Descriptive statistics for cardiac size and other anatomical indices obtained from right lateral radiographs in Texas A&M white quail (*Coturnix* genotype; meat-type white quail, n = 24).

					95% Reference interval	
Variable, mm	Mean ± SD	Min–Max	CV, %	Median	Lower limit (90% CI)	Upper limit (90% CI)
HW	13.44 ± 1.99	10.10–18.41	14.8	13.19	12.75 (12.34–13.16)	14.14 (13.73–14.55)
HL	19.47 ± 2.33	13.16–23.44	11.9	19.33	18.66 (18.19–19.13)	20.29 (19.82–20.76)
SL	54.91 ± 3.83	44.57–60.64	7.0	55.50	53.57 (52.79–54.35)	56.25 (55.47–57.03)
SC	23.59 ± 1.69	20.44–27.30	7.2	24.06	23.00 (22.65–23.35)	24.18 (23.83–24.53)

Abbreviations: HW, widest point of the heart; HL, length of the heart from the aorta and pulmonary artery to the apex; SL, length of the sternum from the insertion of the coracoid to the caudal edge; SC, depth of the sternum, 90° from the junction of the coracoid to the sternum; SD, standard deviation; Min, minimum; Max, maximum; CV, coefficient of variation; CI, confidence interval.

Table 3. The ratio of cardiac width to other anatomic indices from ventrodorsal radiographs in Texas A&M white quail (*Coturnix* genotype; meat-type white quail, n = 24).

					95% Reference interval	
Variable, mm	Mean ± SD	Min–Max	CV, %	Median	Lower limit (90% CI)	Upper limit (90% CI)
CW:TW	0.55 ± 0.06	0.42–0.63	10.5	0.55	0.53 (0.52–0.54)	0.57 (0.56–0.58)
CW:CoW	7.77 ± 1.80	4.08–10.98	23.2	7.52	7.14 (6.77–7.51)	8.40 (8.03–8.77)
CW:RD	3.11 ± 0.49	2.00–3.94	15.7	3.16	2.94 (2.84–3.04)	3.28 (3.18–3.38)
CW:SW	4.26 ± 0.68	3.06–5.52	15.9	4.23	4.02 (3.88–4.16)	4.50 (4.36–4.64)
CW:CID	0.94 ± 0.13	0.73–1.21	14.0	0.92	0.89 (0.86–0.92)	0.98 (0.95–1.01)

Abbreviations: SD, standard deviation; Min, minimum; Max, maximum; CV, coefficient of variation; CI, confidence interval; CW, cardiac width; TW, thoracic width; CoW, coracoid width; RD, distance between the 3rd and 4th ribs; SW, synsacrum width; CID, clavicular distance.

In the present study, the average ClD was 20.75 ± 2.44 mm, and the average CW/ClD ratio was 0.94 ± 0.13. A highly significant positive correlation was found between CW and ClD ($r = 0.539$, $P = 0.003$). The mean ± SD of RD and SW were 6.25 ± 0.43 mm and 4.58 ± 0.53, respectively. No significant correlation was identified between CW and RD ($r = -0.021$, $P = 0.460$) or CW and SW ($r = 0.308$, $P = 0.072$).

DISCUSSION

The aim of this study was to establish reference values for the cardiac silhouette in a supposed healthy flock of Texas A&M white quail. Evaluation of the size and shape of the heart in poultry is performed using VD and right lateral radiography; however, lateral radiography is not considered as reliable due to superposition of the proventriculus and sternum on the cardiac silhouette.[7,10] Therefore, VD radiography was primarily used for the calculations in this study.

In the present study, the mean ± SD CW and TW ratio was 0.55 ± 0.06 (55%). Many studies have reported a strong correlation between CW and TW,[12,15] and CW could be estimated based on TW using the formula identified in this study. Based on these results, TW should be used when evaluating cardiac size in Texas A&M white quail.

Table 4. Pearson correlation coefficient (r) and correlation significance among cardiac width and ventrodorsal radiographic measurements in Texas A&M white quail (*Coturnix* genotype; meat-type white quail).

Item	CW, mm	TW, mm	CID, mm	CoW, mm	SW, mm	RD, mm
CW (mm)	—	0.744*	0.539**	−0.124	0.308	−0.021

Abbreviations: SD, standard deviation; Min, minimum; Max, maximum; CV, coefficient of variation; CI, confidence interval; CW, cardiac width; TW, thoracic width; CoW, coracoid width; RD, distance between the third and fourth ribs; SW, synsacrum width; CID, clavicular distance.

*$P < 0.001$; **$P = 0.003$.

The ratio of CW:TW has been found to vary among avian species from 45% to 75%.[12,16–19] In our study, the average CW of Texas A&M white quail was found to be 55% TW. Migratory birds have been reported to have a larger heart size than nonmigratory birds;[21,25] however, the highest CW/TW ratio was in budgerigars (62%), a nonmigratory psittacine bird.

Cardiac width has been compared with CoW width in many studies. A strong or moderate correlation was detected between the 2 measurements.[12,25] Mirshahi et al[12] reported that the CW:CoW ratio was 7.43 ± 0.53 mm in common kestrels. Barbon et al[19] determined a moderate correlation between CW and CoW in the radiologic evaluation of the cardiac size of 4 falconiform species. Locke et al[25] found a correlation between CW and CoW in bald eagles; however, CoW did not appear to be appropriate in the species reported here because CoW was the smallest measured value, and no significant correlation was identified between CW and CoW.

Limitations of this study include the absence of bloodwork prior to the study, radiographs taken without sedation/anesthesia, the presence of eggs in the coelom (6/12, 50%), and potential human error despite measurements being performed by 3 different individuals.

Table 5. Pearson correlation coefficient (r) and correlation significance among right lateral radiographic measurements in Texas A&M white quail (*Coturnix* genotype; meat-type white quail).

Item	HW	HL	SL	SC
HW	—			
HL	0.609*	—		
SL	−0.094	0.253	—	
SC	0.360	0.356	0.383	—

Abbreviations: HW, widest point of the heart; HL, length of the heart from the aorta and pulmonary artery to the apex; SL, length of the sternum from the insertion of the coracoid to the caudal edge; SC, depth of the sternum, 90° from the junction of the coracoid to the sternum.

* $P = 0.002$.

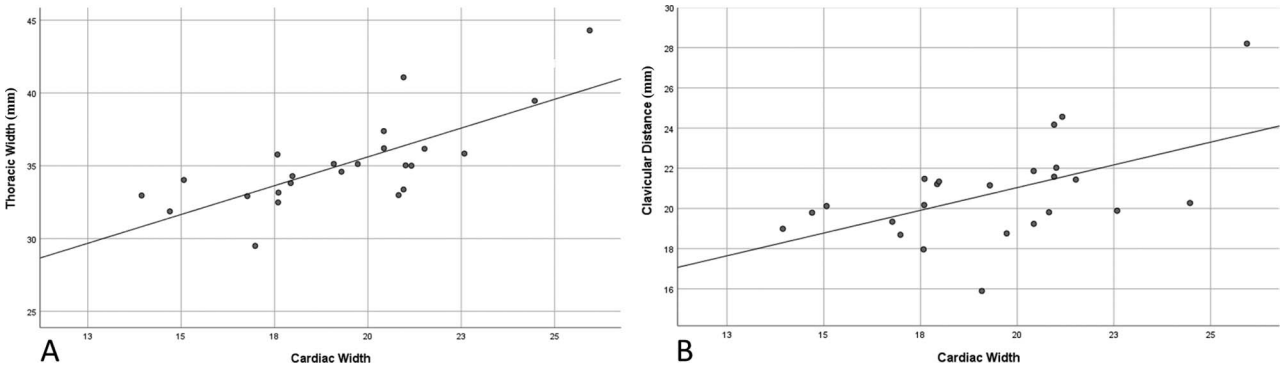

Figure 2. (A) Scatterplot showing the positive correlation between cardiac width and thoracic width of Texas A&M white quail (*Coturnix* genotype; meat-type white quail). Measured from ventrodorsal radiographic projections (n = 24; $R^2 = 0.55$, $P < 0.001$; thoracic width (Y; mm) = 19.78 + 0.79 X (cardiac width [mm]). (B) Scatterplot showing the positive correlation between cardiac width and clavicular distance of Texas A&M white quail (*Coturnix* genotype; meat-type white quail) measured from ventrodorsal radiographic projections (n = 24; $R^2 = 0.29$, $P = 0.007$; clavicular distance (Y; mm) = 11.99 − 0.45 X (cardiac width [mm]).

Future studies could aim for more comprehensive cardiac examinations involving a larger sample size to enhance the accuracy of the reference intervals. The values and ratios obtained in this study can serve as a reference for assessing heart size in Texas A&M white quail radiographs, promoting a more objective evaluation. Additional research to determine how the measured ratios can be used to differentiate between normal cardiac size and cardiomegaly in Texas A&M white quail and deviations from the established reference values may be useful in guiding a clinician toward further cardiac testing.

Acknowledgments: The authors declare no conflicts of interest. This study was approved by the Aydin Adnan Menderes University (ADU) Animal Experiments Local Ethics Committee on April 13, 2023, and numbered 64583101/2023/54. A total of 24 adult Texas Quails (n = 24; 12 females, 12 males) were obtained from the ADU Faculty of Veterinary Medicine, Poultry Research and Practice Unit for this study.

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