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Radiomorphometric studies of the thorax in Nigerian indigenous dog: Novel thoracic measurements

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Abstract

Evaluation of the heart in terms of its silhouette size and shape and the morphometry of other thoracic organs cannot be ignored diagnostically in small animal practice when history and or results of general examination of a patient reveal clinical signs of cardiothoracic diseases. However, there is a paucity of published work on the radiologic appraisal of cardiac and thoracic dimensions in the Nigerian indigenous dog. The research aimed to establish new reference indices for improved diagnosis of cardiothoracic pathologies in the Nigerian indigenous dog. A total of 120 thoracic radiographs of thirty healthy Nigerian indigenous dogs, comprising right lateral, left lateral, dorsoventral and ventrodorsal projections, were obtained and evaluated. Biometric parameters were taken of each research radiographs, recorded, and used to generate cardiothoracic measurement indices for the Nigerian indigenous dog. In the dorsoventral versus ventrodorsal projections, ratios established and described as means plus or minus standard errors of means were as follows: cardiac width/cardiac length ratio 0.75±0.01/0.73±0.01; cardiac length/thoracic diameter 0.64±0.01/0.70±0.01; and heart width/costocostal distance ratio 0.58±0.01/0.60±0.01, respectively. The mean results obtained in the right lateral versus left lateral radiographs were: postcava-to-long axis ratio 0.14±0.00/0.15±0.00; cardiac axes ratio 0.75±0.01/0.81±0.01; cavocardiac ratio 0.19±0.01/0.19±0.01; aorticocardiac ratio 0.22±0.0/0.21±0.00; short axis/sternovertebral distance 0.63±0.01/0.63±0.01; and aortic diameter/long axis ratio 0.17±0.00/0.17±0.00, respectively. The cardiac axes ratio and aorticocardiac ratio showed a positive and significant ($p \leq 0.05$) relationship with the cardiac short axis in the lateral projections. The indices established in this study are reproducible and easy to use, allowing objective thoracic assessment. All the results are efficient and generated in the present investigation, probably, for the first time in veterinary radiology. The clinical relevance of this research is related to the management of cardiothoracic anomalies.

Keywords: Dogs, Measurements, projections, Radiology, Thoracic organs

Introduction

Evaluation of the heart in terms of its silhouette size and shape as well as the morphology of other thoracic organs cannot be ignored diagnostically in Small Animal Clinical Practice when history and or results of general examination of a patient reveal clinical signs of cardiothoracic diseases (Thrall, 2002; Gulanber *et al*., 2005). Clinical signs that prompt thoracic assessment include limb abduction, bulging eyes, neck extension, reluctance to lie down, ascites, syncope, (jugular) venous distension, feeble pulse, water-hammer pulse, oedema, rales, rhonchi, cough, arrhythmias, bradycardia, and tachycardia (Fraser, 1991).

Radiologic diagnosis in Veterinary Medicine is used to identify abnormal (thoracic) organ sizes such as microcardia, cardiomegaly, specific cardiac chamber or great vessel enlargement, pulmonary parenchyma status, vascular anomalies, and determination of pleural fluid (Darke *et al*., 1996; Kittleson 1998). Diseases of other soft tissues and skeletal components, including trachea, bronchi, lungs, oesophagus, pulmonary vasculature, vertebral column, sternum, and ribs are also diagnosed radiologically (Farrow, 1996).

In the past, assessment of thoracic radiographs was restricted to qualitative description of anatomic structures. So, it was subjective and associated with a high error margin. Radiologists and clinicians then used their personal impressions to decide, for instance, whether the heart was enlarged or not. In addition, they considered how much space the heart occupied in the thoracic cavity compared with lung volume; cardiac shape, size and contour; location of trachea, breed and conformation differences (Hansson, 2004). Recently, the application of radiologic measurement methods has proved very sensitive and more accurate in thoracic evaluation, especially in subtle cases of organ size anomaly (e.g. organomegaly), and when used by inexperienced clinicians.

In recent times due to the long-standing cordial relationship between humans and dogs, there has been a remarkable increase in ownership of the Nigerian indigenous dog (NID) for security, companionship, research, hunting, teaching, and other socio-economic purposes (Omudu *et al*., 2010; Aiyedun & Olugasa, 2012; Otolorin *et al*., 2014). The challenges of veterinary clinicians and other small animal health care providers are multiplied as a result of the ever-increasing (indigenous) dog populations.

At this moment, literature is very sparse of research records on the application or development of measurements in clinical diagnosis and treatment of thoracic disease in the Nigerian indigenous dog (NID), resulting in the very low incidence of published cardiothoracic diseases of the indigenous dog breed (Olatunji-Akioye & Alabi, 2015), and probably, increased morbidity and mortality rates in these dogs. It is easily seen that cardiac evaluations, especially by CTR and VHS, constitute the most common thoracic investigation in the small animal practice probably due to unavailability of documented indices that could evaluate anomalies in other thoracic structures. The aim of the present study was to introduce new guides for the evaluation of dimensional changes in the NID associated with the heart, caudal vena cava, thoracic vertebrae, the aorta, and inner pleura-to-pleura distance.

Materials and Methods

The study adopted a prospective cross-sectional design. Thirty clinically healthy dogs of an average body weight 8.19 ± 2.45 kg (range: 4.0 – 15.6 kg) (comprising an equal number of sexes distributed into 20 adults and 10 puppies) were used for the study. The dogs were sampled using the non-probability convenience sampling method. The dogs were acclimatized and kept in separate kennels for four weeks. Within that period, they were fed, dewormed and screened for cardiovascular diseases by physiologic examination. Vital parameters (heart rate, rectal temperature, respiratory rate, pulse rate, mucous membrane colour, and capillary refill time) obtained of each animal were within the normal ranges recorded for the canine species. Therefore, the dogs were deemed suitable for the research (Straub *et al*., 2002). Each animal was identified with numbered plastic pendants, restrained with xylazine hydrochloride (XYL–M2®, VMD, Belgium) at 2.0mg/kg i.m and ketamine hydrochloride (Ketanir®, Aculife Healthcare, India) injected i.m. at 10mg/kg, and positioned with leg-ties and sandbags for thoracic radiography. A mobile X-ray machine, Dean Dynamax 40 (GEC Medical Equipment Group Ltd, England) was used for the study. Focus-film-distance and object-film-distance were set at 90 cm and 0 cm, respectively, for all the exposures. Kilovoltage and milliamperage settings were varied with thoracic thicknesses of the dogs. The same brand of blue-sensitive X-ray film (Begood®, Medical X-ray, China) was used to evaluate all the animals. Exposed films were then processed. A total of 120 right lateral (RtL), left lateral (LeL), dorsoventral (DV) and ventrodorsal (VD) canine thoracic projections were obtained and evaluated.

Radiographic measurements (Plates I and II) were taken in each of the research radiographs with a pair of calipers and a transparent metre rule. In the DV/VD views, parameters measured were cardiac diameter (CD), cardiac length (CL), thoracic diameter (TD), heart width (HW) and costocostal distance (CC). In the RtL/LeL projections, sternovertebral distance (SV) or a line between mid-points of the inner surfaces of tenth thoracic vertebra (T10) and the xyphoid cartilage (XC) (Kilda *et al*., 2007; Rebeis *et al*., 2007), diameter of the tenth thoracic vertebra (VD) measured from the dorsum to the ventral surface of the T10 in line with SV, postcaval diameter (PC) i.e. the widest transverse diameter of the caudal vena cava, aortic transverse diameter (AD) i.e. the maximum transverse diameter of the descending aorta, cardiac long axis (LA), and short axis (SA) were all measured and recorded. The measured dimensions were utilized to generate index

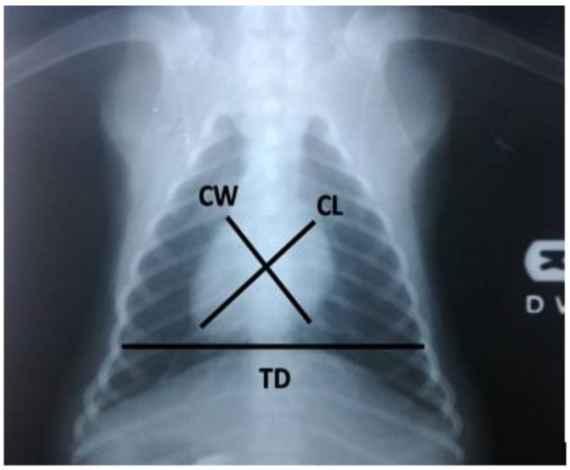

Plate I (a): Dorsoventral thoracic radiograph of a healthy Nigerian indigenous dog showing parameters measured for the determination of thoracic ratios. CL = cardiac length, CW = cardiac width, TD = thoracic diameter

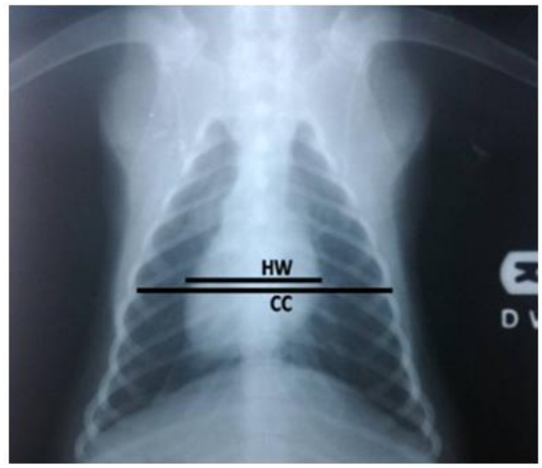

Plate I (b): Dorsoventral radiograph of a healthy Nigerian indigenous dog showing parameters measured for the determination of thoracic ratios. HW = heart width, CC = costocostal distance

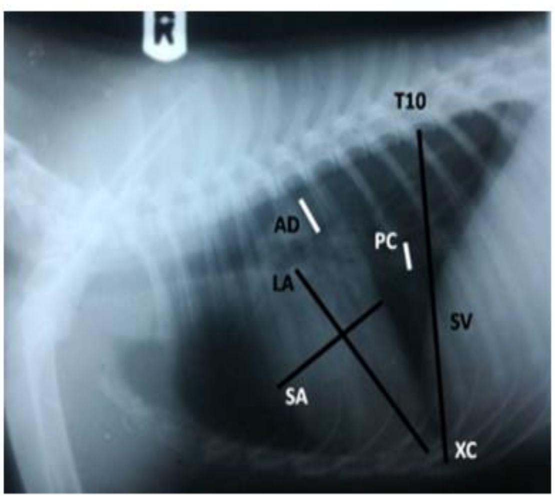

Plate II (a): Lateral thoracic radiograph of a Nigerian indigenous dog with illustrations of parametric measurements for index development. LA = long cardiac axis, SA = short axis, PC = postcaval diameter, AD = aortic diameter, VD = vertebral diameter, T10 = tenth thoracic vertebra, SV = sternovertebral distance, XC = xiphoid cartilage

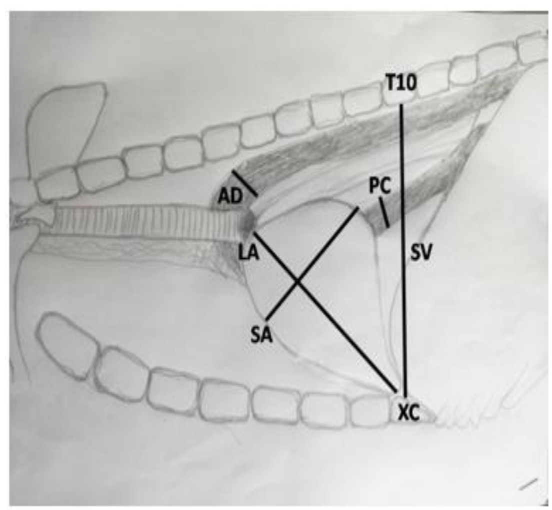

Plate II (b): Annotated diagram of a lateral thoracic radiograph of a Nigerian indigenous dog with illustrations of parametric measurements for index development (See legends in Plate II a).

references for cardiothoracic measurements in the NID. The indices established were cardiac length-to-thoracic diameter ratio, CL/TD; heart width-to-costocostal distance ratio, HW/CC; and cardiac width-to-cardiac length ratio, CW/CL; postcava-to-long axis ratio, PC/LA; cardiac axes ratio, CAR (SA/LA); cavocardiac ratio, CCR (PC/SA); aorticocardiac ratio, ACR (AD/SA); short axis-to-sternovertebral ratio (SA/SV); and aortic diameter-to-long axis ratio, AD/LA.

Data analysis

Results were presented as means ± standard errors of means while differences between mean values and associations of the means with thoracic parameters were subjected to student's t-test and correlation coefficient statistics using SPSS version 22 for windows. A probability value less than or equal to five percent ($p \leq 0.05$) was considered statistically significant.

Results

In Table 1a, presented mean cardiac width (CW) and mean cardiac length (CL) values were slightly bigger in DV radiographs compared with their respective mean values in VD views. However, mean cardiac width-to-cardiac length (CW/CL) ratios were greater in VD projections. The female CW/CL ratios were greater in DV views than in VD views; but there was not a difference between the male DV versus VD mean indices (Table 1b). There was no difference in puppy mean CW/CL ratios between the DV and VD views; whereas, DV mean CW/CL ratio was slightly greater than VD mean value in the adult dogs (Table 1b).

As shown in Table 2a, CL/TD mean ratio was slightly smaller in (DV) radiographs than the mean value in the VD views. In both male and female radiographs, the DV and VD CL/TD mean ratios were greatly similar (Table 2b). In the DV versus VD radiographs of both puppies and adult dogs, there was no variation in CL/TD mean values evaluated (Table 2b). As illustrated in Table 3a, mean HW/CC ratio was slightly smaller in DV views than its mean value in VD radiographs (Table 3a). HW/CC means are slightly less in male DV versus VD radiographs compared with female index means in both views (Table 3a). There was no variation between adult and puppy HW/CC means in DV radiographs; but adult dog HW/CC index mean was slightly less than puppy mean value in VD radiographs. As shown in Table 4a, PC/LA index mean in the RtL views is less than the index value obtained in the LeL views. Female PC/LA means in both RtL and LeL radiographs were a little greater than PC/LA ratio means evaluated in the RtL and LeL male projections (Table 4b). In the puppies, PC/LA mean ratios in both RtL and LeL views were slightly greater than PC/LA mean ratios obtained for adult dogs (Table 4b).

In Table 5, the mean short axis (SA) was shorter in RtL views than its LeL mean value, but the reverse was the case for the mean long axis (LA), resulting in the RtL mean cardiac axes ratio (CAR) being smaller than the LeL mean value. Male CAR means were smaller than the

Table 1a: Cardiac width-to-cardiac length (CW/CL) ratios in dorsoventral and ventrodorsal radiographs of the Nigerian indigenous dog

CW/CL indices	Dorsoventral (DV) views	Ventrodorsal (VD) views
CW	5.64±0.11	5.85±0.11
CL	7.57±0.15	8.00±0.17
CW/CL	0.75±0.01	0.73±0.01

Ratio means not significantly different from each other (P≥0.05)

Table 1b: Sex and age differences in CW/CL ratios in dorsoventral and ventrodorsal radiographs of the Nigerian indigenous dog

Sex differences				
CW/CL ratios	DV (Females)	VD (Females)	DV(Males)	VD (Males)
CW	5.66±0.12	5.84±0.12	5.63±0.19	5.86±0.19
CL	7.56±0.17	8.07±0.22	7.59±0.25	7.93±0.27
CW/CL	0.75±0.01	0.73±0.01	0.74±0.01	0.74±0.01
Age differences				
CW/CL indices	DV (Adults)	VD (Adults)	DV (Puppies)	VD (Puppies)
CW	5.90±0.11	6.12±0.10	5.14±0.12	5.32±0.12
CL	7.97±0.14	8.51±0.13	6.78±0.11	7.00±0.11
CW/CL	0.74±0.01	0.72±0.01	0.76±0.01	0.76±0.01

Sex ratio means not significantly different from each other (P≥0.05), in respective projections

Age ratio means not significantly different from each other (P≥0.05), in respective projections

Table 2a: Cardiac length/thoracic diameter (CL/TD) ratios determined in dorsoventral and ventrodorsal radiographs of the Nigerian indigenous dog (Mean and SEM)

CL/ TD indices	Dorsoventral (DV) views	Ventrodorsal (VD) views
CL	7.57±0.15	8.00±0.17
TD	11.86±0.27	11.44±0.28
CL/TD	0.64±0.01	0.70±0.01

Ratio means not significantly different from each other (P≥0.05)

Table 2b: Sex and age differences in CL/TD ratios determined in dorsoventral and ventrodorsal radiographs of the Nigerian indigenous dog (Mean and SEM)

		Sex differences		
CL/ TD indices	DV (Females)	VD (Females)	DV (Males)	VD (Males)
CL	7.56±0.17	8.07±0.22	7.59±0.25	7.93±0.27
TD	11.88±0.31	11.55±0.38	11.84±0.44	11.34±0.43
CL/TD	0.64±0.01	0.70±0.01	0.64±0.01	0.70±0.02
		Age differences		
CD/ TD indices	DV (Adults)	VD (Adults)	DV (Puppies)	VD (Puppies)
CL	7.97±0.14	8.51±0.13	6.78±0.78	7.00±0.81
TD	12.51±0.27	12.15±0.27	10.57±0.22	10.04±0.17
CL/TD	0.64±0.01	0.70±0.01	0.64±0.01	0.70±0.01

Sex index means not significantly different from each other (P≥0.05) in respective projections
Index means of adult and puppy not significantly different from each other (P≥0.05), in respective views

Table 3a: Heart width/costocostal distance (HW/CC) ratios in dorsoventral and ventrodorsal thoracic radiographs of the Nigerian indigenous dog (Mean and SEM)

HW/CC indices	DV views	VD views
HW	5.79±0.12	5.91±0.13
CC	10.04±0.21	9.84±0.24
HW/CC ratio	0.58±0.01	0.60±0.01

Ratio means not significantly different from each other (P≥0.05)

Table 3b: Sex and age differences in HW/CC ratios in dorsoventral and ventrodorsal thoracic radiographs of the Nigerian indigenous dog (Mean and SEM)

		Sex differences		
HW/CC indices	DV (Females)	VD (Females)	DV (Males)	VD (Males)
HW	5.89±0.15	6.01±0.18	5.69±0.19	5.81±0.19
CC	10.11±0.20	9.88±0.28	9.98±0.36	9.79±0.39
HW/CC	0.58±0.01	0.61±0.01	0.57±0.01	0.60±0.02
		Age differences		
HW/CC indices	DV (Adults)	VD (Adults)	DV (Puppies)	VD (Puppies)
HW	6.08±0.13	6.21±0.14	5.22±0.60	5.32±0.61
CC	10.55±0.18	10.42±0.21	9.03±1.05	8.67±1.01
HW/CC	0.58±0.01	0.60±0.01	0.58±0.01	0.62±0.01

Sex ratio means not significantly different from each other (P≥0.05) in respective views
Age index means not significantly different from each other (P≥0.05) in respective views

Table 4a: Postcava/long axis (PC/LA) ratios determined in right lateral and left lateral thoracic radiographs of the Nigerian indigenous dog (Mean and SEM)

PC/LA indices	Right Lateral (RtL) Views	Left Lateral (LeL) Views
PC	1.20±0.03	1.20±0.03
LA	8.30±0.18	7.79±0.19
PC/LA ratio	0.14±0.00	0.15±0.00

Ratio means not significantly different from each other (P≥0.05)

Table 4b: Sex and age differences in postcava/long axis (PC/LA) ratios determined in right lateral and left lateral thoracic radiographs of the Nigerian indigenous dog (Mean and SEM)

		Sex differences		
PC/LA indices	Right Lateral View (Females)	Left Lateral View (Females)	Right Lateral View (Males)	Left Lateral View (Males)
PC	1.21±0.05	1.21±0.05	1.18±0.04	1.18±0.04
LA	8.27±0.22	7.72±0.22	8.33±0.31	7.85±0.32
PC/LA ratio	0.15±0.00	0.16±0.00	0.14±0.00	0.15±0.00
		Age differences		
PC/LA Indices	Right Lateral View (Adults)	Left Lateral View (Adults)	Right Lateral View (Puppies)	Left Lateral View (Puppies)
PC	1.27±0.03	1.27±0.03	1.05±0.12	1.05±0.12
LA	8.81±0.14	8.28±0.18	7.27±0.84	6.80±0.79
PC/LA ratio	0.14±0.00	0.15±0.00	0.15±0.02	0.15±0.02

Ratio means of both sexes are not significantly different from each other (P≥0.05) in respective projections
Age mean ratios are not significantly different from each other (P≥0.05) in respective projections

Table 5a: Cardiac axes ratio obtained in the right lateral and left lateral thoracic radiographs of Nigerian indigenous dogs; measurements in cm. CAR=SA/LA (Mean and SEM)

Cardiac Axes indices	Right Lateral Views	Left Lateral Views
SA	6.18±0.12	6.24±0.13
LA	8.29±0.18	7.78±0.19
CAR	0.75±0.01	0.80±0.01

Ratio means are not significantly different from each other (P≥0.05)

Table 5b: Sex and age cardiac axes ratio in right lateral and left lateral thoracic radiographs of male and female Nigerian indigenous dogs; CAR=SA/LA (Mean and SEM)

		Sex differences		
CAR indices	RtL (Females)	LeL (Females)	RtL (Males)	LeL (Males)
SA	6.26±0.17	6.34±0.18	6.10±0.18	6.15±0.20
LA	8.27±0.22	7.72±0.22	8.33±0.31	7.85±0.32
CAR	0.76±0.01	0.82±0.01	0.74±0.01	0.79±0.01
		Age differences		
CAR indices	RtL (Adults)	LeL (Adults)	RtL (Puppies)	LeL (Puppies)
SA	6.51±0.10	6.60±0.11	5.52±0.64	5.53±0.64
LA	8.81±0.14	8.28±0.18	7.27±0.84	6.80±0.79
CAR	0.74±0.01	0.80±0.01	0.76±0.09	0.82±0.09

Ratio means of both sexes are not significantly different from each other (P≥0.05) in respective projections
Age mean ratios are not significantly different from each other (P≥0.05) in respective projections

female than the female means in both RtL and LeL radiographs (Table 5b). Puppy mean CAR values were greater than mean CARs for adult dogs in both RtL and LeL radiographs (Table 5b). As seen in Table 6a, RtL and LeL cavocardiac ratios (CCR) were not varied. Female CCR means were slightly greater than the male mean value in the RtL and LeL views (Table 6b). Puppy mean CCR values were slightly more than the CCR indices obtained for the adult dogs in both lateral (RtL and LeL) views (Table 6b).

In Table 7a, aortic diameter (AD) mean in RtL projections was slightly more than AD mean value in LeL views. However, short axis (SA) mean was less in RtL views than its mean value in LeL views. Aorticocardiac ratio (ACR) mean in RtL views was a little more than the ratio calculated in LeL radiographs (Table 7b). Mean values of female aortic diameter (AD), SA and ACR were all slightly greater than their respective male mean indices in both RtL and LeL views (Table 7b). In adult dogs, RtL and LeL AD and SA means were slightly greater than their respective means in puppies.

Table 6a: Cavo-cardiac ratio in right lateral and left lateral thoracic radiographs of Nigerian indigenous dogs; CCR = PC/SA (Mean and SEM)

Cavocardiac indices	Right lateral views	Left lateral views
PC	1.20±0.03	1.20±0.03
SA	6.25±0.13	6.25±0.13
CCR	0.19±0.01	0.19±0.01

Ratio means are not significantly different from each other (P≥0.05)

Table 6b: Cavo-cardiac ratios and age differences of lateral thoracic radiographs in male and female Nigerian indigenous dogs; CCR=PC/SA (Mean and SEM)

Sex differences				
CCR indices	RtL (Females)	LeL (Females)	RtL (Males)	LeL (Males)
PC	1.21±0.05	1.21±0.05	1.18±0.04	1.18±0.04
SA	6.35±0.18	6.34±0.18	6.16±0.20	6.15±0.20
CCR	0.19±0.01	0.19±0.01	0.19±0.00	0.19±0.00
Age differences				
CCR indices	RtL (Adults)	LeL (Adults)	RtL (Puppies)	LeL (Puppies)
PC	1.27±0.03	1.27±0.03	1.05±0.12	1.05±0.12
SA	6.61±0.11	6.61±0.11	5.55±0.64	5.53±0.64
CCR	0.19±0.01	0.19±0.01	0.19±0.02	0.19±0.02

Ratio means of both sexes are not significantly different from each other (P≥0.05), in respective projections
Age mean ratios are not significantly different from each other (P≥0.05), in respective projections

Table 7a: Aorticocardiac ratio obtained in right lateral and left lateral thoracic radiographs of Nigerian indigenous dogs; ACR = AD/SA (Mean and SEM)

ACR indices	**Right lateral views**	**Left lateral views**
AD	1.37±0.03	1.33±0.03
SA	6.18±0.12	6.24±0.13
ACR	0.22±0.00	0.21±0.00

Ratio means are not significantly different from each other (P≥0.05)

Table 7b: Aorticocardiac ratios in right lateral and left lateral thoracic radiographs of male and female Nigerian indigenous dogs; ACR= AD/SA

Sex differences				
ACR indices	RtL (Females)	LeL (Females)	RtL (Males)	LeL (Males)
AD	1.41±0.03	1.38±0.04	1.33±0.05	1.29±0.04
SA	6.26±0.17	6.33±0.18	6.10±0.18	6.15±0.20
ACR	0.23±0.01	0.22±0.01	0.22±0.01	0.21±0.00
Age differences				
ACR indices	Right lateral view (Adults)	Left lateral view (Adults)	Right lateral view (Puppies)	Left lateral view (Puppies)
AD	1.43±0.02	1.39±0.03	1.25±0.15	1.22±0.14
SA	6.51±0.10	6.60±0.11	5.52±0.64	5.53±0.64
ACR	0.22±0.01	0.21±0.01	0.23±0.01	0.22±0.01

Ratio means of both sexes are not significantly different from each other (P≥0.05), in respective projections
Ratio means of both ages are not significantly different from each other (P≥0.05), in respective projections

However, ACR mean values were greater in puppies (Table 7b).

As shown in Table 8a, short axis-to-sternovertebral (SA/SV) ratios were not varied between the RtL and LeL views studied. SA/SV index means were not different between female RtL and female LeL views, but the male RtL index mean was slightly less than male LeL value (Table 8b). The LeL mean SA/SV ratio in adult dogs was a little greater than its RtL mean value; but in puppies,

RtL mean SA/SV index mean was greater than LeL puppy mean ratio (Table 8b).
As in Table 9a, mean RtL values of AD and LA were slightly greater than their respective mean values obtained in LeL projections, but mean AD/LA ratios were not different between the lateral views studied. However, female AD means were slightly greater in RtL and LeL views than male AD mean values in those views, respectively; but male LA means were greater in RtL and LeL views than its respective values in female radiographs (Table 9b). Female AD/LA mean ratios are slightly greater than male AD/LA mean values, in both RtL and LeL views. Mean AD and mean LA values were both slightly greater in RtL and LeL views of adult dogs.

Table 8a: Short axis-to-sternovertebral (SA/SV) ratios in right lateral and left lateral thoracic radiographs of Nigerian indigenous dogs (Mean and SEM)

Sternovertebral indices	Right lateral views	Left lateral views
SA	6.18±0.12	6.25±0.13
SV	9.91±0.21	9.95±0.24
SA/SV ratio	0.63±0.01	0.63±0.01

Ratio means are not significantly different from each other (P≥0.05)

Table 8b: Sex and age differences short axis-to-sternovertebral (SA/SV) ratios obtained in right lateral and left lateral thoracic radiographs of male and female Nigerian indigenous dogs (Mean and SEM)

		Sex differences		
SA/SV indices	RtL (Females)	LeL (Females)	RtL (Males)	LeL (Males)
SA	6.26±0.17	6.34±0.18	6.10±0.18	6.15±0.20
SV	9.97±0.27	10.09±0.32	9.84±0.37	9.81±0.37
SA/SV ratio	0.63±0.01	0.63±0.01	0.62±0.01	0.63±0.01
		Age differences		
SA/SV indices	RtL view (Adults)	LeL view (Adults)	RtL view (Puppies)	LeL view (Puppies)
SA	6.51±0.10	6.61±0.11	5.52±0.64	5.53±0.64
SV	10.50±0.16	10.51±0.20	8.72±1.02	8.84±1.04
SA/SV ratio	0.62±0.01	0.63±0.01	0.64±0.01	0.63±0.01

Ratio means of both sexes are not significantly different from each other (P≥0.05), in respective projections
Ratio means of both age brackets are not significantly different from each other (P≥0.05), in respective views

Table 9a: Aortic diameter-to-long axis ratios (AD/LA) in right lateral and left lateral thoracic radiographs of Nigerian indigenous dogs (Mean and SEM)

AD/LA indices	Right lateral views (RtL)	Left lateral views (LeL)
AD	1.37±0.03	1.33±0.03
LA	8.29±0.19	7.79±0.19
AD/LA	0.17±0.00	0.17±0.00

Ratio means are not significantly different from each other (P≥0.05), in both projections

Table 9b: Aortic diameter/long axis (AD/LA) ratios in right lateral and left lateral thoracic radiographs of male and female Nigerian indigenous dogs (Mean and SEM)

		Sex differences		
AD/LA indices	RtL (Females)	LeL (Females)	RtL (Males)	LeL (Males)
AD	1.41±0.03	1.38±0.04	1.33±0.05	1.29±0.04
LA	8.26±0.23	7.73±0.22	8.33±0.31	7.83±0.32
AD/LA	0.17±0.01	0.18±0.01	0.16±0.00	0.16±0.00
		Age difference		
AD/LA indices	RtL (Adults)	LeL (Adults)	RtL (Puppies)	LeL (Puppies)
AD	1.43±0.02	1.39±0.03	1.25±0.15	1.22±0.14
LA	8.82±0.14	8.28±0.18	7.25±0.84	6.81±0.79
AD/LA	0.16±0.00	0.17±0.00	0.17±0.01	0.18±0.00

Ratio means of both sexes are not significantly different from each other (P≥0.05), in respective projections
Age ratio means are not significantly different from each other (P≥0.05), in respective projections

Table 10: Pooled ranges, variances, and means of thoracic ratios determined in radiographs of the NID

Index	View	Range	Variance	Pooled Mean ± SEM
CAR:	RtL	0.66-0.81	0.0011	0.75±0.01
	LeL	0.71-0.87	0.0017	0.81±0.01
CCR:	RtL	0.16-0.21	0.0001	0.19±0.01
	LeL	0.17-0.21	0.0001	0.19±0.01
ACR:	RtL	0.19-0.27	0.0004	0.22±0.00
	LeL	0.19-0.25	0.0003	0.21±0.00
SA/SV:	RtL	0.53-0.70	0.0019	0.63±0.01
	LeL	0.54-0.70	0.0019	0.63±0.01
AD/LA:	RtL	0.14-0.21	0.0002	0.17±0.00
	LeL	0.14-0.21	0.0003	0.17±0.00
PC/LA:	RtL	0.12-0.16	0.0001	0.14±0.00
	LeL	0.13-0.18	0.0002	0.15±0.00
HW/CC:	DV	0.49-0.64	0.0015	0.58±0.01
	VD	0.47-0.69	0.0027	0.60±0.01
CW/CL:	DV	0.64-0.82	0.0019	0.75±0.01
	VD	0.68-0.82	0.0016	0.73±0.01
CL/TD:	DV	0.55-0.71	0.0018	0.64±0.01
	VD	0.61-0.79	0.0027	0.70±0.01

Full meanings of abbreviations are provided in Plates I and II

Mean (AD/LA) ratios were a little greater in puppy radiographs than their values derived in lateral views of the adult dog (Table 9b). Table 10 provides a cursory look at the various result ranges, mean ratios, and variances of pooled sample indices established in the present investigation in stipulated radiographic projections. From the table, it can be seen that the levels of difference from the expected results (or variances) were minimal and negligible in all the mean ratios obtained in this research.

Discussion

Exploratory surgery revealed that the heart of flying fox species elongates during systole and is globoid in diastole (Kallen, 1970), which, according to Schmidt-Nielsen (1997) and Machida & Aohagi (2001), may be an adaptation for flight, as the bat's heart shares certain features with avian heart. However, the multiple radiographs evaluated in this study showed insignificant differences in cardiac measurements, suggesting that the cardiac cycle phase has little or no impact on the radiographic appearance of the heart in the NID. This finding has already been documented as a fact in other animals by Norman *et al.* (1971), Toal *et al.* (1985), Baron (2004), and Gardner *et al.* (2007). It has already been noted that cardiac evaluations, especially cardiothoracic ratio (CTR) and vertebral heart size VHS, constitute the most common thoracic investigation in the small animal practice, probably due to the unavailability of documented indices that could evaluate anomalies in other thoracic organs. The following ratios were introduced in the present study as new methods for the investigation of various dimensional changes in the NID associated with the heart, caudal vena cava, thoracic vertebrae, the aorta, and the costocostal distance, namely: heart width-to-costocostal ratio (HW/CC), cardiac width-to-cardiac length (CW/CL), cardiac length-to-thoracic diameter (CL/TD) indices (in dorsoventral and ventrodorsal projections) and cardiac axes (CAR), cavo-cardiac ratio (CCR), aortico-cardiac ratio (ACR), post cava-to-long axis ratio (PC/LA), short axis-to-sternovertebral index (SA/SV) and aortic diameter-to-long axis ratios (AD/LA) (in lateral views). The mean indices between the DV/VD and RtL/LeL projections, sexes and age groups were not significantly ($p \geq 0.05$) different. In the dorsoventral (DV) views, the CW/CL pooled sample result was slightly greater than the mean ratio obtained in the ventrodorsal (VD) views and vice versa for the HW/CC indices. These results confirm Carlisle and Thrall's (1982) earlier report that the DV versus VD cardiac silhouette size variation in the dog was not pronounced. Contrarily, and in healthy West African dwarf goats, Ukaha and Kene (2010) found that the DV heart image was globoid as in generalized cardiomegaly, whereas the VD cardiac image was seen to be conical or gourd-shaped, the normal cardiac appearance. However, there is a stark similarity of CL/TD and CCR index means generated in the radiographs of the pooled sample, sexes and age brackets, respectively. This finding is probably a pointer to a high degree of reliability of these indices, which could be effective for the radiographic measurement of cardiac parameters, thoracic breadth, postcaval diameters, and rib-to-rib dimensions.

The left lateral (LeL) cardiac axes ratio (CAR) mean values were consistently slightly greater than the right lateral (RtL) values, but there was no statistical mean CAR difference ($p \geq 0.05$) between each pair of the views. The reason for the CAR means values being greater in LeL than RtL views was because cardiac long axes were clearly longer in the right lateral projections. This could probably be due to the influence of the cardiophrenic ligament on the cardiac silhouette size and appearance. The ligament is attached to the left side of the cardiac apex from the diaphragm (Dyce *et al.*, 1987) so that when the dog was on left lateral recumbency, the apex was held back by the ligamentous attachment, away from the sternum, and assumed a shorter silhouette in that view.

Respiratory phases do not influence the CAR unlike CTR which varies with stages of respiration and must be obtained at the peak of inspiration. CAR correlated significantly, strongly and positively with cardiac short axis ($p<0.003$). Therefore, CAR would be useful for the diagnosis of canine cardiac size anomaly. Cavo-cardiac ratio, CCR, is equally not influenced by breathing (inspiration/expiration) phases. The mean CCR values we established in the present research were not significantly different between sexes, adult dogs and puppies, and RtL/LeL radiographic views ($p \geq 0.05$). The similarities of the CCR means within and across result pairs (sexes, ages and views) were striking. CCR could be used to evaluate diametric size changes of the caudal vena cava in the NID.

We got mean aortic-cardiac ratios (ACRs) in the RtL versus LeL projections of both sexes and age brackets that were not significantly different from each other ($p \geq 0.05$). The LeL ACR means were slightly less than the corresponding RtL results all the time, though the differences lacked statistical significance. The ACR could be a useful index for the evaluation of dimensional changes of the aortic arch, as well as heart sizes. The ratio SA/SV (short axis-to-sternovertebral distance ratio) was determined in this research with mean results not significantly varied ($p \geq 0.05$) in sexes, ages and lateral radiographs. Sternovertebral distance is a good indicator in the pre- and post-operative assessment of thorax for *pectus* deformation.

Bahr (2013) reported that the postcaval size was extremely variable depending on the animal's health status, respiratory phase and cardiac cycle and that, due to its normal size variation, valid references to cardiovascular pathology cannot typically be established on the basis of the diameter of the caudal vena cava alone. However, the results of this study obtained in the NID are in stark contrast with Bahr's report because the postcaval indices (CCRs and PC/LA ratios) are reliable and efficient based on their negligible variances (Gardner *et al.*, 2007). A parameter that is "extremely variable" may hardly yield a reliable index like we found with postcaval diameter in the NID. In the present investigation, we got similar caval diameter means in both RtL and LeL views ($p \geq 0.05$). However, and based on the present result, the postcava can be adjudged to be enlarged if its diameter is larger than 1.6 centimetres. Additionally, Lehmukhl *et al.* (1997) suggested that the postcaval vein should be considered enlarged if it is consistently larger than 1½ times the diameter of the descending aorta. Therefore, valid references to cardiovascular pathology may be established in the NID on the basis of postcaval diameter. All the same, Root and Bahr (2002) opined that right-sided congestive heart failure should be considered if the caudal vena cava is persistently large; but if the caval vein is small in both lateral and dorsal/ventral projections, or in repeated radiographs, hypovolaemia should be considered. In the dog, Root and Bahr (2002) and Bahr (2013) also found that dilatory cardiomyopathy is often associated with pulmonary oedema secondary to left ventricular failure in addition to radiographic signs of right-sided heart failure: distension of postcava, hepatic enlargement, and pleural effusion.

All the mean indices, especially CCR, ACR, AD/LA and PC, were associated with very low variances indicating negligible levels of difference from expected results and are therefore reliable and efficient measurement ratios based on the report of Gardner *et al*. (2007). Cardiothoracic ratio (CTR) is clearly the most common method of cardiac assessment in both man and animals. However, Birkemeier *et al.* (2011), Albertal *et al.* (2013), and Hassan *et al.* (2019) believe that phase of respiration has a significant influence on thoracic conformation. As a result, thoracic diameter and CTR assume different values with respiratory phases. For this reason, radiographs used for CTR study are usually exposed in the inspirational phase, thereby ruling out the phasic respiratory difference on the thoracic diameter size. A challenge that cannot easily be overcome in veterinary radiography, especially by radiology students and inexperienced clinicians, is to obtain repeated thoracic radiographs of a patient at the same level (e.g. peak) of inspiration in order to standardize the thoracic diameter value. The new ratios developed in this research (except the CL/TD and HW/CC) are not affected by the phases of respiration. They therefore are believed by the authors to be better and more efficient than CTR for heart size evaluation.

It is interesting to note that the most efficient ratios were obtained in the laterolateral recumbent projections. These findings suggest that the lateral radiographs may be more sensitive and adequate for the evaluation of cardiac and other thoracic organ silhouettes. Therefore, when radiographic examination for diagnostic purposes must be made subjectively in the NID, the lateral view (especially left lateral radiograph) seems more preferable because most thoracic organs/structures are better visualized in the lateral radiographs as against the superposition of some organs when the animal is X-rayed in dorsoventral plane. Another advantage is the ease and convenience of positioning a dog on its side compared to dorsal-ventral recumbency. The DV should be preferred to the VD roentgenographs for operator convenience and patient comfort in orthogonal evaluations. The results of this study provide a handy guide in the thoracic radiographic evaluation, in clinical practice and biomedical research, of the NID.

It should be reiterated that most of the indices established in the present investigation are efficient and reliable for thoracic measurement. However, validation of the results with clinical cases of cardiothoracic disease awaits research. The results of this research are all radiographic; they should be correlated with thoracic organ function test results and computed tomographic findings.

The index results obtained in this research may be useful guidelines in small animal clinical practice in the NID prequel to the application of other modalities, e.g., echocardiography and computed tomography, or for comparison and assessment of thoracic organs in the common scenario where radiography is the only available facility for research and diagnosis.

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