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Assessment of the thorax is equivalent when presented with whole body versus collimated thoracic radiographs in dogs and cats

Manabu Kurihara[1*], Mauricio Solano[2] and Tomoki Motegi[3]

Abstract

Background Analog radiographic techniques traditionally focus on collimation to enhance diagnostic quality by limiting the field to the area of interest. With digital radiology systems, this study hypothesized that whole-body radiographs are diagnostically equivalent to collimated thoracic radiographs. Conducted at a university teaching hospital from November 2019 to April 2021, the study involved 40 client-owned small-breed dogs and cats presenting with respiratory or cardiovascular complaints. Each animal underwent both whole-body radiographs and collimated thoracic radiographs, and the radiographs were evaluated by three board-certified radiologists and three general practitioners in a blinded, randomized manner, based on a 12-question Likert scale survey.

Results Diagnostic assessments of thoracic findings were equivalent between whole-body radiographs and collimated thoracic radiographs, with no significant differences identified by the six reviewers, irrespective of their level of expertise. These findings confirm that whole-body radiographs and collimated thoracic radiographs are diagnostically comparable for identifying thoracic abnormal findings, including cardiomegaly ($n = 19$), bronchial pattern ($n = 12$), esophageal dilation ($n = 7$), alveolar pattern (presumably pneumonia) ($n = 6$), narrowing of the trachea and bronchi ($n = 5$), left-sided congestive heart failure ($n = 4$), pleural effusion ($n = 4$), rib fractures ($n = 2$), pulmonary mass/nodule ($n = 2$), transitional vertebrae ($n = 2$), intrathoracic lymphadenopathy ($n = 1$), and hypovolemia ($n = 1$).

Conclusions The study supports whole-body radiographs as a practical alternative to collimated thoracic radiographs for evaluating thoracic abnormal findings in small animals. WBR offers a simpler imaging approach without compromising diagnostic accuracy, providing a flexible and reliable option in clinical practice.

Keywords Radiography, Digital radiography, Collimation, Radiographic techniques

*Correspondence:
Manabu Kurihara
mkuriha@ncsu.edu
[1]Department of Molecular and Biological Sciences, College of Veterinary Medicine, North Carolina State University, 1060 William Moore Drive, Raleigh, NC 27607, USA
[2]Department of Clinical Sciences, Cummings School of Veterinary Medicine at Tufts University, 200 Westboro Rd, North Grafton, North Grafton, MA 01536, USA
[3]Cooperative Department of Veterinary Medicine, Faculty of Agriculture, Tokyo University of Agriculture and Technology, Harumicho, 3–8–1, Fuchu, Tokyo 183-8538, Japan

Background

In a standard radiographic protocol, the x-ray primary beam is aimed to the center of any given region of interest [1]. The x-ray beam is also collimated to eliminate any other adjacent area that is not of clinical interest [1]. This protocol is commonly taught to radiology students during their DVM curriculum. When using analog film-screen systems, the increased scattered radiation of an uncollimated beam generated by the tissues outside the area of interest results in decreased radiographic contrast. Increasing volume of tissue, field size, tube kilovoltage, and the density of matter all contributes to scattered radiation. In addition, a wider, divergent primary beam results in distortion and magnification of the structures at the periphery of the collimated field, reducing the sharpness of tissue which results in a decreased spatial resolution [2]. As a result, interpretation of areas at the periphery of the primary beam must be done with caution. In settings where quality control is not overseen by a radiologist or trained radiology technician, whole-body radiographs (WBR) are commonly performed, particularly in private practice. The most frequent example is capturing both the thorax and abdomen of small dogs and cats in a single projection. These uncollimated studies are often preferred due to their ease of execution, time efficiency, and potential cost savings. However, the increasing workload in veterinary practice poses significant challenges. The American Veterinary Medical Association (AVMA) recognizes the widespread stress in the profession and emphasizes the need for data-driven solutions to address workforce shortages, enhance productivity, and support veterinary teams. [3] Financial considerations are also becoming increasingly important in veterinary medicine. Studies suggest that pet health insurance increases spending per veterinary visit without affecting visit frequency, indicating that pet owners are willing to invest more in veterinary care. [4] However, cost discussions between veterinarians and clients remain infrequent, despite the growing financial commitment of pet owners. This highlights the need for improved communication about financial options to ensure pet owners can make informed decisions regarding their pets' healthcare. [5] For instance, one study found that providing information on veterinary costs and disease risks increased pet insurance uptake by 12.3%, underscoring the role of financial education in veterinary practice. [6] These factors suggest that while WBR may offer practical benefits, their use must be considered in the broader context of workforce challenges, financial constraints, and the evolving role of veterinarians in guiding pet owners through both medical and financial decisions.

Previous studies comparing different projections have been published. In the thorax, they include comparing a left lateral versus right lateral views to evaluate differences in position, size, and shape of the cardiovascular and pulmonary structures [7], dorsoventral versus ventrodorsal views to assess cardiovascular structures [8], and two views versus three views in assessing interstitial lung disease including metastases [9]. In the abdomen, studies to evaluate gastrointestinal disease [10] and acute abdomen have also been performed [11]. An online literature search (PubMed and Google Scholar using the following keywords "comparison," "collimation", "thoracic radiograph", "collimated thoracic", "thoracic ", "thorax", "whole-body radiograph", "whole-body", "radiograph", "canine", "dog", "feline", "cat", from 1963 to present revealed no literature comparing WBR to CTR.

This study compares the radiology assessment of WBR to the assessment of CTR of the same patient using a DR system. The authors hypothesized that with DR, due to its higher contrast resolution and exposure latitude [12, 13], including thorax and abdomen in a single projection will not result in a decrease in the diagnostic quality of the study, and as such, the final assessment of WBR will not differ from CTR. Furthermore, the study results may help highlight the potential clinical benefits of WBR, including time efficiency, cost-effectiveness, and improved patient management.

Methods

Selection and description of subjects

The present diagnostic method comparison study was conducted under the approval of the Tufts Cummings School of Veterinary Medicine Clinical Studies Review Committee. Forty client-owned animals (25 cats and 15 dogs) with a body length up to 43 centimeters (17 inches), measured from manubrium to the coxofemoral joints, were recruited at The Henry & Lois Foster Hospital for Small Animals at Tufts University. These animals fit within the size of the standard 36 × 43 centimeters (14 × 17 inches) flat panel detector used. The patients were prospectively recruited over an 18-month period from November 2019 to April 2021. The patients were presented with primary complaints of acute or chronic respiratory or cardiovascular diseases including tachycardia, tachypnea, heart murmur, cough, abnormal pulmonary sounds, and anorexia. Patients with severe clinical signs were excluded due to difficulties of obtaining four radiographic projections.

Data recording and analysis

Right lateral and ventrodorsal CTR and WBR were taken on each patient for a total of 80 studies. Sedation was administered as needed using commonly used sedatives, including dexmedetomidine, butorphanol, diazepam, and acepromazine. CTR included the thorax from the manubrium to a few centimeters caudal to the last rib, while WBR included the thorax and abdomen from the

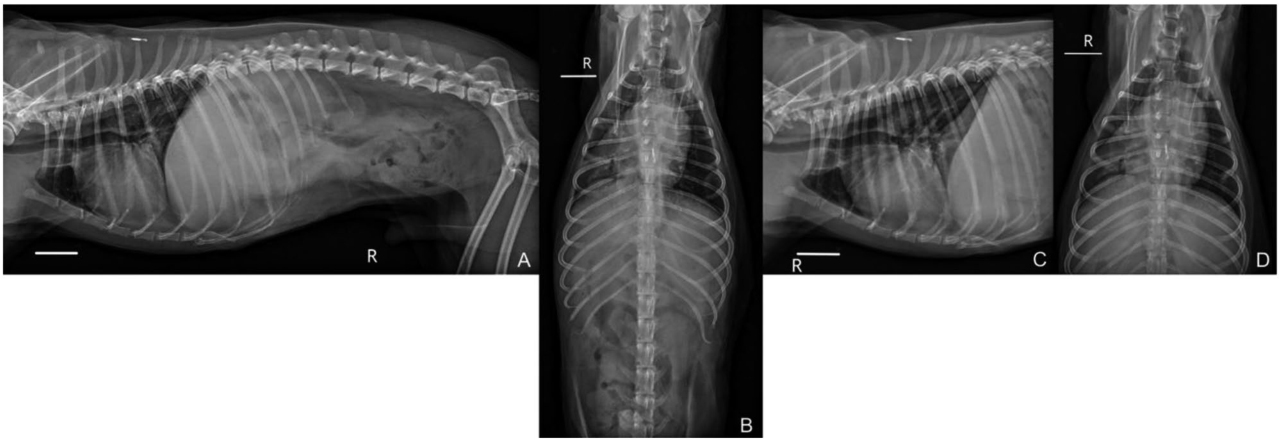

Fig. 1 Whole-body radiographs in right lateral projection (**A**) and ventrodorsal projection (**B**), along with collimated thoracic radiographs in right lateral projection (**C**) and ventrodorsal projection (**D**). There is an increased soft tissue opacity with air bronchogram (alveolar pattern) in the right middle lung lobe and dorsal aspect of the cranial segment of left cranial lung lobe, most likely consistent with pneumonia. A small amount of gas is visible in the esophagus. Serosal detail is reduced; however, abdominal findings are not included in the evaluation. Scale bar = 3.0 cm

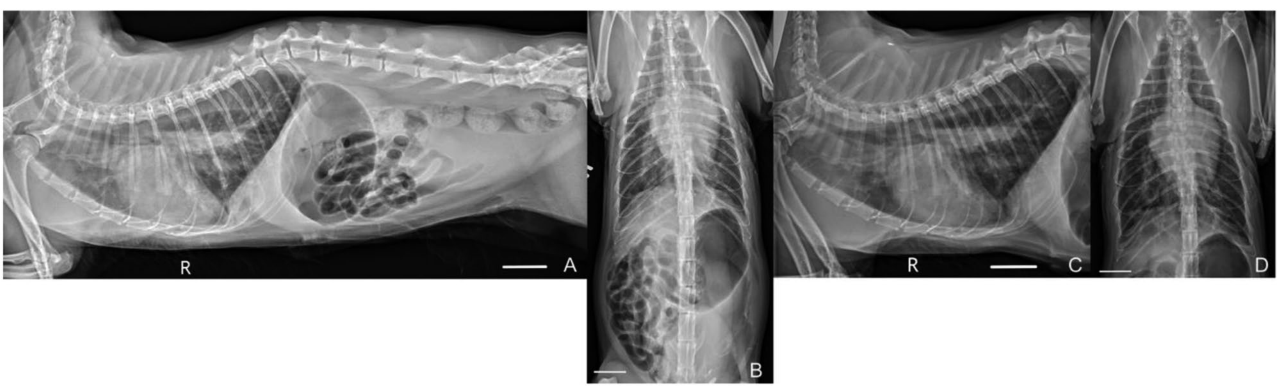

Fig. 2 Whole-body radiographs in right lateral projection (**A**) and ventrodorsal projection (**B**), along with collimated thoracic radiographs in right lateral projection (**C**) and ventrodorsal projection (**D**). The cardiac silhouette is moderately enlarged with dilated pulmonary vasculature. There is mild, diffuse interstitial and bronchial pattern throughout the lungs, likely indicative of left-sided congestive heart failure. A moderate amount of gas is present in the caudal aspect of the esophagus. Scale bar = 3.0 cm

manubrium to the coxofemoral joints with images centering on mid-aspect of the body such as last ribs (Figs. 1, 2 and 3). Both CTR and WBR were taken at maximum inspiration. Appropriate mAs and kVp were determined for each individual patient based on patient's thickness. For small dogs, 80 kVp and 3.2 mAs and 90 kVp and 3.2 mAs were used for the right lateral and ventrodorsal views, respectively. In cats, 80 kVp and 2.5 mAs was used for both right lateral and ventrodorsal views. A 14 × 17 Cesium Iodide (Csl) based, static flat panel detector (Canon Digital Radiography Systems CXDI-501G 14 × 17, Canon Medical Systems, Tustin, CA) interfaced with image post processing software (Sound Smart DR, Carlsbad, CA) was used. The obtained CTR and WBR for each patient were anonymized, randomized (1 to 80), and stored as Digital Imaging and Communications in Medicine (DICOM) format on a local patient archiving and communication system software (Carestream PACS Vue Motion, Version 12. 1, Carestream Health inc., Rochester, NY). The authors (MK and MS), a diagnostic imaging resident, and an American College of Veterinary Radiology (ACVR)-certified veterinary radiologist evaluated the studies, separately and later by consensus to determine if an abnormal finding was present or absent using a Likert scale. These results were referred to as the agreement scale.

Three ACVR-certified veterinary radiologists with at least three years in practice, and three licensed general practitioners (GP) with at least ten years of experience were asked to answer a 12-question survey related to the radiographs. The reviewers were not affiliated with the hospital and had no previous knowledge of the patient's clinical history or the study design. The reviewers were asked to determine if there were abnormal findings within the set of images and graded their degree of certainty on a Likert scale as follows: 1- I am certain this

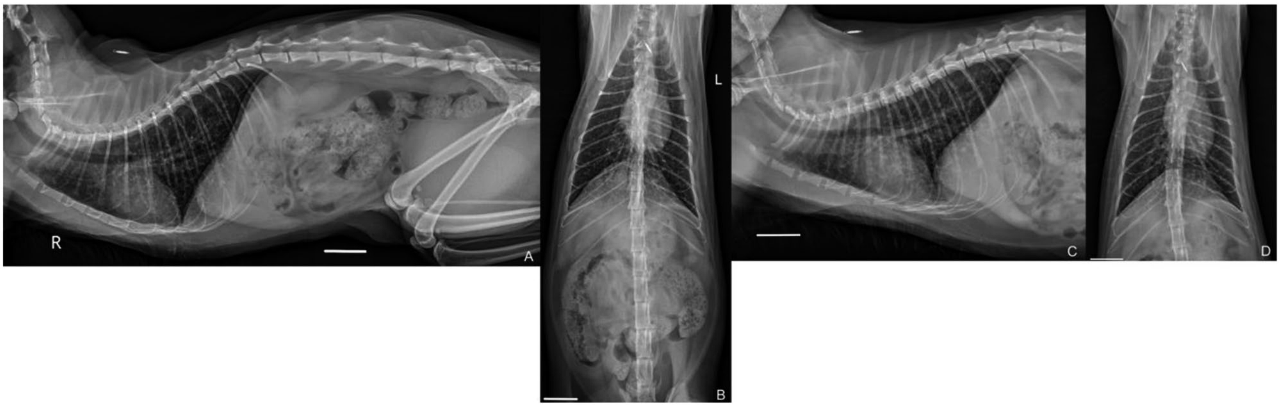

Fig. 3 Whole-body radiographs in right lateral projection (**A**) and ventrodorsal projection (**B**), along with collimated thoracic radiographs in right lateral projection (**C**) and ventrodorsal projection (**D**). A moderate bronchial pattern is present throughout the lungs. Scale bar = 3.0 cm

finding is not present., 2- I am somewhat certain this finding is not present., 3- I cannot determine whether this finding is present or not., 4- I am somewhat certain this finding is present., and 5- I am certain this finding is present. The 12 questions included: cardiomegaly, left-sided congestive heart failure, hypovolemia, narrowing of trachea and bronchus, bronchial pattern, alveolar pattern (presumably pneumonia), esophageal dilation, pulmonary masses or nodules, pleural effusion, intrathoracic lymphadenopathy, rib fractures, and transitional vertebrae. An open-ended question that allowed the reviewers to add additional comments (50 words limit) was also provided. A time limit to evaluate the studies was not given.

Statistical analysis

The answers to the 12 questions on a Likert scale had a total of 5,760 points and were analyzed using a normal distribution. A parametric analysis using t-tests following previous studies was performed [14].

The agreement scale generated by the authors was compared to the scale generated by the radiologists and GP (reviewer scale). The equivalence of evaluation between agreement scale and reviewers' scales was defined as the difference of t-distribution being between plus or minus 10% (Δ) from zero point [15]. When a confidence interval lies within – Δ and Δ, equivalence between the reviewer scale and the agreement scale is present. On the other hand, when a confidence interval is outside – Δ and Δ, equivalence between the reviewer scale and the agreement scale is not present. Questions outside the agreement scale were further analyzed with Fischer's exact test to assess the rate of acceptable concordance. The latter was defined as the difference of a Likert scale from zero or one in each question. All statistical analyses were performed by an independent statistician (TM) using R (ver 4.2.2; R Foundation for Statistical Computing, Vienna, Austria).

Results

The data consisted of 25 cats and 15 dogs. Of the 25 cats, 14 were males, and 11 were females. Five dogs were male, and 10 were female. The median age of the feline patients was 9 years (range: 5 months – 17 years), and that of the dogs was 10 years (range: 1 month – 15 years). The median weight in cats was 4.6 kg (range: 2.2–6.6 kg) and in dogs, 4.2 kg (range: 1.2–9.2 kg). Cat breeds included Domestic Shorthair ($n = 20$), Main Coon (2), and one of each Domestic Medium hair, Domestic Longhair, and Siamese. Dog breeds included Shih Tzu (3), Poodle (3), Chihuahua (2), and one of each of the following breeds: Jack Russell Terrier, Labrador Retriever, Pug, Dachshund, Pomeranian, English bulldog, and Maltese.

Tested radiographic abnormal findings included cardiomegaly ($n = 19$), bronchial pattern (12), esophageal dilation (7), alveolar pattern (presumably pneumonia) (6), narrowing of trachea and bronchus (5), left-sided congestive heart failure (4), pleural effusion (4), rib fractures (2), pulmonary mass/nodule (2), transitional vertebrae (2), intrathoracic lymphadenopathy (1), and hypovolemia (1).

Six categories of 95% intervals for each question were generated: CTR for three radiologists, three GP, and six reviewers and WBR for three radiologists, three GP, and six reviewers. All confidence intervals for the six reviewers lay within the equivalence range (–Δ and Δ). That is, for the six reviewers and both CTR and WBR, the agreement scale and the reviewer scale were equivalent.

The upper bounds of the confidence intervals of the cardiomegaly in the CTR and WBR for the GP extended beyond Δ (Fig. 4). Therefore, assessment of cardiomegaly in both CTR and WBR by the GP was not equivalent to the agreement scale. Also, the lower bounds of the confidence intervals of hypovolemia and intrathoracic lymphadenopathy (Fig. 4) in the CTR for the GP were less than -Δ. The assessment of hypovolemia and lymphadenopathy by the GP was not equivalent to the agreement scale when presented with CTR. The radiologist assessment

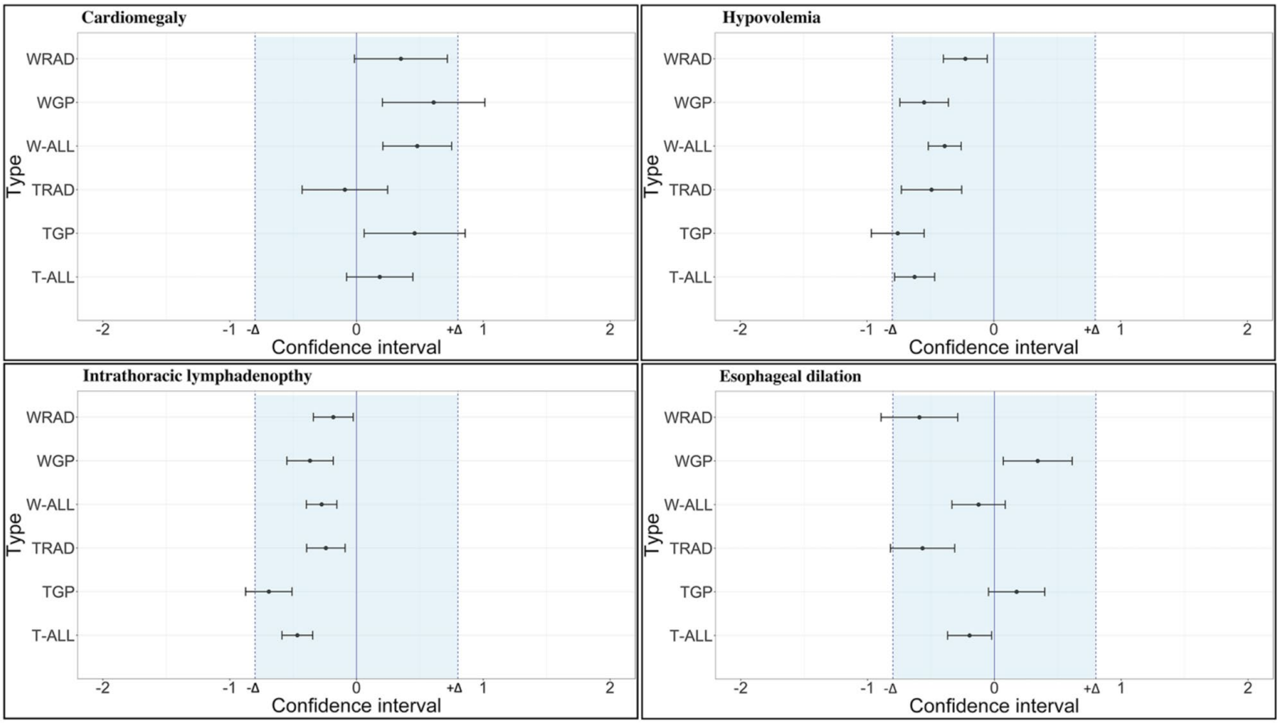

Fig. 4 Results associated with cardiomegaly, hypovolemia, intrathoracic lymphadenopathy, and esophageal dilation

Table 1 Results of Fisher's exact test of six inequivalent items in which the confidence intervals did not lie between – Δ and Δ

Question	Type	*P*-value	Odds ratio
Cardiomegaly	WGP	1	1.034
Cardiomegaly	TGP	1	1.034
Hypovolemia	TGP	0.044*	0.507*
Esophageal dilation	WRAD	0.114	1.738
Esophageal dilation	TRAD	0.114	1.738
Intrathoracic lymphadenopathy	TGP	0.234	0.628

Abbreviations: WRAD, whole-body radiographs for radiologist; WGP, whole-body radiographs for general practitioners; TRAD, collimated thoracic radiographs for radiologist; TGP, collimated thoracic radiographs for general practitioner

for esophageal dilatation (Fig. 4) was not equivalent to the agreement scale for both WBR and CTR.

For the four questions and six items in which the confidence intervals did not lie between – Δ and Δ, a Fisher's exact test was performed. These items included cardiomegaly in the WBR and CTR, hypovolemia in the CTR and intrathoracic lymphadenopathy in CTR for the GP, esophageal dilation in the WBR and CTR for the radiologists (Table 1). The reviewer scale concordant or non-concordant with the agreement scale were recollected into 2 × 2 contingency tables based on the two factors (WBR and CTR) for each item. There is no statistically significant difference in five items between the WBR and CTR (Table 1). There is statistically significant difference in the evaluation of hypovolemia between the WBR and CTR for the GP ($P = 0.044$ and Odds = 0.507). When the data was divided into two categories whether hypovolemia was present (Likert 5) or not present (Likert 1), the numbers of concordance or non-concordance to the agreement scale were retracted in the CTR and WBR. In the category of absent hypovolemia (Likert 1), the numbers of concordance or non-concordance with the agreement scale in the CTR were 86 and 31 as well as in the WBR were 99 and 18, respectively. P value was 0.053 and Odds ratio was 0.506. On the other hand, in the category of present hypovolemia (Likert 5), the numbers of concordance or non-concordance with the agreement scale in the CTR were 0 and 3 as well as in the WBR were 1 and 2, respectively. The category of present hypovolemia was not evaluated due to a shortage of data.

One case had pneumoperitoneum secondary to intestinal perforation. Two radiologists added an additional comment that pneumoperitoneum was present in the WBR, whereas the same radiologists mentioned possibilities of pneumoperitoneum in the CTR.

When presented with collimated thoracic radiographs, the assessment of general practitioners for cardiomegaly, for both CTR and WBR was not equivalent to the author's agreement scale. When presented with collimated thoracic radiographs, the assessment of general practitioners for hypovolemia and lymphadenopathy was also not equivalent to the author's agreement scale. Assessment of esophageal dilatation by the radiologists was not equivalent for both CTR and WBR to the author's agreement scale. Abbreviations: WRAD, whole-body radiographs for radiologist; WGP, whole-body radiographs for general practitioners; W-ALL, whole-body radiographs for six reviewers; TRAD, collimated thoracic radiographs for radiologist; TGP, collimated thoracic radiographs for general practitioner; T-ALL, collimated thoracic radiographs in six reviewers.

Discussion

In the present study, there is no significant difference in most of the evaluations of the specific thoracic findings between the CTR and WBR and between GP and radiologists. The authors argue that the technological features of a DR system contribute to the equivalence of interpretation between CTR and WBR. In comparison to film-screen systems, a DR system has a broad exposure latitude [12]. The image post processing software of a DR system can compensate for the wide range of thickness of the patient and assigns a suitable gray shade to pixels in the thick and thin regions of a body part [12]. As a result, structures with different x-ray attenuation properties (e.g., bone versus lung) can be appropriately depicted simultaneously in a single image in a DR system [16]. Practically speaking, this provides the operator with a larger margin of error when choosing exposure settings. Specifically, an operator may choose exposure factors that might not be technically adequate to a given tissue thickness and tissue density; however, the resultant image still has adequate diagnostic quality. This is contrary to analog radiographs in which small errors in exposure settings are likely to cause overexposure or underexposure yielding images of low diagnostic quality [17]. The present data supports the practice of assessing both the thorax and abdomen as presented in WBR. The final assessment of an ACVR-certified veterinary radiologist or an experienced private practitioner does not change when presented with CTR or a WBR. This is likely due to the wide exposure latitude and higher contrast resolution of a DR system. Moreover, WBR may eliminate the need for multiple exposures, reducing radiation exposure to both patients and staff. This approach not only streamlines workflow by reducing the time required for image acquisition but also minimizes the need for patient repositioning, which can be particularly beneficial in critically ill or unstable animals. Additionally, decreasing the number of exposures and simplifying the imaging process may contribute to lower costs for pet owners while maintaining diagnostic accuracy. Reducing time in the imaging suite and decreasing the cost of medical care to pet owners may be added bonuses. These advantages make WBR a practical and efficient option in veterinary radiology.

The GP had a tendency to statistically overestimate hypovolemia in the CTR compared to the WBR. While The GP were more likely to underestimate cardiomegaly in the CTR and WBR, there is no statistical significance between their interpretation between CTR and WBR. Several factors can be considered regarding the assessment of cardiomegaly and hypovolemia. Each GP assessed the data differently and were not provided with specific criteria on how to determine if cardiomegaly or hypovolemia were present or not. One used the vertebral heart score (VHS), one used subjective criteria and one also measured the diameter of the pulmonary vessels relative to the ribs at the overlap of a caudal lobe pulmonary artery and vein with the ninth rib [18]. To generate the agreement scale, the authors used a subjective assessment to determine heart size. While VHS and Vertebral Left Atrial Score (VLAS) are effective tools for measuring the size of heart [19–21], comparing between two different methodologies for the purpose of this study may have confounded the findings. Arguably, measurements of VHS, VLAS and diameter of the pulmonary vessels relative to the ninth ribs should not be used on WBR because these measurements have been validated only for CTR. The authors are of the opinion that overreliance in radiographic measurements alone should not be emphasized as suggested elsewhere [22].

The GP tended to overestimate intrathoracic lymphadenopathy in the CTR. However, no statistical significance between the WBR and CTR was found. Factors that may have affected these results include assigning an abnormal value to the normal extra pleural sign in right lateral projections [23]. The reviewers did not have the option to evaluate a left lateral projection to further ascertain with more confidence if sternal lymphadenopathy was or was not present. Also, in the survey, reviewers were not asked to specify which intrathoracic node was abnormal and may have group together sternal, cranial mediastinal or tracheobronchial lymph nodes. We speculate this question did not correctly indicate the appropriate area to be evaluated. If evaluation criteria of lymph nodes had been set appropriately and three view radiographs were included for evaluation, the authors speculate overestimation of thoracic lymphadenopathy by GP might not have occured.

Although the assessment of esophageal dilation by the radiologists was not equivalent to the agreement scale for both CTR and WBR, there is no statistical significance between the CTR and WBR assessments. The radiologists were more likely to overestimate esophageal dilation in the CTR and WBR. It is possible that the radiologists may have judged an esophagus to be dilated when a normal bolus of fluid or gas was detected.

In the one case of pneumoperitoneum the radiologists correctly diagnosed the abnormal finding in the WBR study. This was not diagnosed with the CTR. The differences are not attributed to any potential differences in technical quality between WBR versus CTR but to the fact the area in question was simply not included in the CTR.

Finally, while the additional time spent in the imaging suite and the cost of taking more radiographs per patient was not calculated in this study, the authors argue that taking two radiographs including thorax and abdomen is faster and possibly less expensive than taking four radiographs of the same patient. Nationwide, the average veterinary expenditure per visit has risen due to increased labor costs, rising costs of medical equipment and supplies contributing to more expensive veterinary care.[4–6] Taking WBR may help manage time spent in the imaging suite and the cost of the radiographic study without compromising the diagnostic value of the imaging study.

There are several limitations to this study. In regards to the study group, while age, and species are appropriate, breed distribution is limited. More subjects of chondrodystrophic conformation would have been of benefit. Also, the sample size of this cohort is small and while the studied abnormal findings are commonly found in practice, only a specify set of diseases were included which inherently narrows the clinical application of the study. For example, this selection bias was introduced by virtue of excluding cases with severe clinical signs or patients unlikely to comply with four radiographic projections. As a result, diseases associated with severe radiographic abnormal findings, such as severe pleural effusion or large pulmonary masses were not tested. Additional studies including a larger sample size and a wide variety of diseases in different breed conformations and targeting specific patient groups are needed for further evaluation.

The images were taken by well-trained veterinary technicians with an exclusive focus in producing diagnostic studies at an academic institution. Good image quality in terms of positioning and exposure factors was the norm, which resulted in little differences between CTR and WBR. Therefore, the results cannot be fully extrapolated directly to a setting in which quality control is not fully implemented.

The clinical outcome of each case, more advanced imaging modalities (e.g., echocardiography and computed tomography), and pathological confirmation were not obtained. The agreement scales were based on the authors' radiographic findings. While this study evaluated the level of equivalence between the interpretations of board-certified radiologists and general practitioners, it is important to recognize that the agreement does not necessarily indicate a confirmed diagnosis.

Different types of biases have the potential to affect this type of study. There is an intrinsic central tendency bias associated with the use of a Likert scale. This has been noted when readers who are not confident in their abilities, will tend to select answer closer to the central range of the scale (3- I cannot determine whether this finding is present or not). Also, bias due to participant behavioral changes, known as the Hawthorne effect, can also be introduced [24, 25]. There is also the potential to introduce response bias if a reviewer realizes some of the cases belong to the same patient even if the studies are anonymized.

The use of a Likert scale leaves little room for the nuance often used by radiologists such as degrees of severity (mild, moderate, and severe). This was noted in the case of esophageal dilatation. By using a Likert scale methodology, readers were forced to decide between a yes-or no type of answer. The authors speculate that allowing readers to interpret with degrees of severity, esophageal dilation might not have occurred. In other words, while a Likert scale allows for a simple study design, it places limits on the performance of both less experienced readers as well as radiologists when assessing specific point of interest.

Conclusions

This study has shown that assessment of a set of specific thoracic abnormal findings is equivalent if a reader (radiologists or general practitioners) is presented with whole body radiographs (WBR) or collimated thoracic radiographs (CTR). For WBR to replace CTR for thoracic diseases, we need to subject this technique to many more patients of different body types and a wider range of diseases. However, this study provides evidence that a reader will reach similar radiographic conclusions using WBR or CTR. Hence, WBR generated with a standard DR system can be considered for use in practice without fear of compromising the final radiographic assessment. Reducing time in the imaging suite and decreasing the cost of medical care to the pet owners may be added bonuses.

Abbreviations

CTR Collimated thoracic radiographs
WBR Whole body radiographs
GP General practitioner

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Author contributions

Study conception and design: MK, MS; Acquisition of data: MK; Analysis and Interpretation of Data: MK, MS, TM; Drafting the article: MK, MS; Revising article for intellectual content: MK, MS, TM; All authors read and approved the final manuscript.

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Data availability
The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
All procedures involving animals in this study were approved by the Clinical Studies Review Committee, which serves as the ethics committee of the Tufts Cummings School of Veterinary Medicine (Protocol number: G2018-137). All experiments were carried out in accordance with institutional guidelines and regulations. All owners were informed consents and gave the written consent for allowing their animals to be parts of this study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References
1. Thrall DE, Widmer WR. Radiation protection and physics of diagnostic radiology. In: Thrall DE, editor. Textbook of veterinary diagnostic radiology. 7th ed. St Louis: Saunders Elsevier; 2018. pp. 2–22.
2. Bushberg JT, Seibert JA, Leidholdt EM Jr, Boone JM. Image quality. In: Bushberg JT, editor. The essential physics of medical imaging. 4th ed. Philadelphia: Wolters Kluwer; 2021. pp. 72–108.
3. Salois M, Golab G. Are we in a veterinary workforce crisis? Understanding our reality can guide Us to a solution. J Am Vet Med Assoc. 2021;259(6):560–6.
4. Williams A, Williams B, Hansen CR, Coble KH. The impact of pet health insurance on dog owners' spending for veterinary services. Animals. 2020;10(7):1162.
5. Groves CN, Janke N, Stroyev A, Tayce JD, Coe JB. Discussion of cost continues to be uncommon in companion animal veterinary practice. J Am Vet Med Assoc. 2022;260(14):1844–52.
6. Chiu LJ, Li J, Lhermie G, Cazer C. Analysis of the demand for pet insurance among uninsured pet owners in the united States. Vet Rec. 2021;189(1):e243.
7. Spencer C, Ackerman N, Burt J. The canine lateral thoracic radiograph. Veterinary Radiol. 1981;22(6):262–6.
8. Ruehl WW Jr, Thrall DE. The effect of dorsal versus ventral recumbency on the radiographic appearance of the canine thorax. Veterinary Radiol. 1981;22(1):10–6.
9. Ober CP, Barber D. Comparison of two-vs. three-view thoracic radiographic studies on conspicuity of structured interstitial patterns in dogs. Vet Radiol Ultrasound. 2006;47(6):542–5.
10. Armbrust LJ, Biller DS, Hoskinson JJ. Case examples demonstrating the clinical utility of obtaining both right and left lateral abdominal radiographs in small animals. J Am Anim Hosp Assoc. 2000;36(6):531–6.
11. Mavromatis MV, Solano M, Thelen MY. Utility of two-view vs. three-view abdominal radiography in canines presenting with acute abdominal signs. Vet Radiol Ultrasound. 2018;59(4):381–6.
12. Robertson ID, Thrall DE. Digital radiographic imaging. In: Thrall DE, editor. Textbook of veterinary diagnostic radiology. 7th ed. St Louis: Saunders Elsevier; 2018. pp. 23–38.
13. Widmer WR. Acquisition hardware for digital imaging. Vet Radiol Ultrasound. 2008;49:S2–8.
14. DeWees TA, Mazza GL, Golafshar MA, Dueck AC. Investigation into the effects of using normal distribution theory methodology for likert scale patient-reported outcome data from varying underlying distributions including floor/ceiling effects. Value Health. 2020;23(5):625–31.
15. Piaggio G, Elbourne DR, Altman DG, Pocock SJ, Evans SJ, CONSORT Group FT. Reporting of noninferiority and equivalence randomized trials: an extension of the CONSORT statement. JAMA. 2006;295(10):1152–60.
16. Mattoon JS. Digital radiography. Veterinary Comp Orthop Traumatol. 2006;19(03):123–32.
17. Nuth EK, Armbrust LJ, Roush JK, Biller DS. Identification and effects of common errors and artifacts on the perceived quality of radiographs. J Am Vet Med Assoc. 2014;244(8):961–7.
18. Bahr RJ. Canine and feline cardiovascular system. In: Thrall DE, editor. Textbook of veterinary diagnostic radiology. 7th ed. St Louis: Saunders Elsevier; 2018. pp. 684–709.
19. Duler L, Visser LC, Jackson KN, Phillips KL, Pollard RE, Wanamaker MW. Evaluation of radiographic predictors of left heart enlargement in dogs with known or suspected cardiovascular disease. Vet Radiol Ultrasound. 2021;62(3):271–81.
20. Malcolm EL, Visser LC, Phillips KL, Johnson LR. Diagnostic value of vertebral left atrial size as determined from thoracic radiographs for assessment of left atrial size in dogs with myxomatous mitral valve disease. J Am Vet Med Assoc. 2018;253(8):1038–45.
21. Keene BW, Atkins CE, Bonagura JD, Fox PR, Häggström J, Fuentes VL, Oyama MA, Rush JE, Stepien R, Uechi M. ACVIM consensus guidelines for the diagnosis and treatment of myxomatous mitral valve disease in dogs. J Vet Intern Med. 2019;33(3):1127–40.
22. Lamb CR, Nelson JR. Diagnostic accuracy of tests based on radiologic measurements of dogs and cats: a systematic review. Vet Radiol Ultrasound. 2015;56(3):231–44.
23. Dennis R, Kirberger RM, Barr Frances, Wrigley RH. Handbook of small animal radiology ultrasound techniques and differential diagnoses; chap. 8 other thoracic structures: pleural cavity, mediastinum, thoracic oesophagus, thoracic wall. 2nd ed. Missouri: Saunders Elsevier; 2010. pp. 199–228.
24. Delgado-Rodriguez M, Llorca J, Bias. J Epidemiol Community Health. 2004;58(8):635–41.
25. Wickström G, Bendix T. The Hawthorne effect—what did the original Hawthorne studies actually show? Scand J Work Environ Health. 2000 Aug;1:363–7.

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