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ASSESSMENT OF RESPIRATION-INDUCED DISPLACEMENT OF CANINE ABDOMINAL ORGANS IN DORSAL AND VENTRAL RECUMBENCY USING MULTISLICE COMPUTED TOMOGRAPHY

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Abstract

Respiratory-induced organ displacement during image acquisition can produce motion artifacts and variation in spatial localization of an organ in diagnostic computed tomography (CT) exams. The purpose of this prospective study was to quantify respiratory-induced abdominal organ displacement in dorsal and ventral recumbency using five normal dogs. All dogs underwent CT exams using 64-multidetector-row computed tomography (MDCT). A “3-dimensional (3D) apneic CT exam” of the abdomen was acquired followed by a “4-dimensional (4D) ventilated CT exam”. The liver, pancreas, both kidneys, both medial iliac lymph nodes and urinary bladder were delineated on the 3D–apneic exam and the organ outlines were compared to the maximum alteration in organ position in the 4D–ventilated exam. Displacement was measured in dorsal-to-ventral (DV), right-to-left (RL) and cranial-to-caudal (CC) directions. Respiratory-induced displacement of canine abdominal organs was not predictable and showed large variability in the three directions evaluated. For most canine abdominal organs, dorsal recumbency provided overall the least amount of displacement among all directions evaluated except for liver and urinary bladder. For liver, a large variability was found for all directions and a statistically significant difference was found only in RL direction with ventral recumbency exhibiting less displacement ($P = 0.0099$). For the urinary bladder ventral recumbency also provided less displacement but this was statistically significant only in the RL direction ($P < 0.0001$). Findings from this study indicated that dorsal recumbency may be preferred for whole abdomen studies, but ventral recumbency may be preferred for liver and urinary bladder studies when respiration cannot be controlled.

Keywords

computed tomography; displacement; recumbency; respiration; radiotherapy

Introduction

Respiratory-induced organ displacement during image acquisition can produce motion artifacts and variation in spatial localization of an organ in diagnostic computed tomography (CT) exams. Motion artifact can appear as blurred organ margins or transposition of the plane of an organ between slices in the transverse plane and stair step artifact when evaluating dorsal and sagittal plane reconstructions.¹ The increasing use of multi-slice CT units in veterinary diagnostic imaging enables increasingly rapid acquisition of abdominal exams that can be kept mostly free of respiratory artifact by an induced short apnea. However many institutions operate or acquire single detector-row CT units that require extended apnea to avoid respiratory-induced motion artifacts, which may not be feasible in a given patient. Although the protocols for patient recumbency may change based on operator preference and depending on the organ of interest, a recommendation to use ventral recumbency for CT of all abdominal organs has been given in a textbook.¹ This recommendation is currently not based on scientific evidence in veterinary medicine.

When CT studies are acquired for radiation therapy planning, the organ position at the time of CT exam is used for delineating the target volumes and the organs at risk.² Respiratory organ motion may introduce inaccurate organ localization and may therefore influence the accuracy of delineated target volumes and organs at risk.² By accounting for intrafractional organ displacement, higher doses can potentially be delivered to target volumes improving tumor control and reducing late complications resulting from dose delivery to organs at risk.³

In humans, studies evaluating organ displacement are usually performed using respiratory-gated CT in which exam acquisition can be correlated to the patient's respiratory cycle. Where conventional CT exams acquired on MDCT units in helical mode deliver superior anatomical information of the acquired volume (3D exam), 4D exams also include the anatomical variations over time. For 4D CT exams, multiple images are acquired over one anatomical region during several tube rotations. Surface markers, bellows placed around the patient's lower thorax or upper abdomen, or spirometers are used to monitor the respiratory cycle phase and the CT exam can then be either manually or automatically triggered for a predefined duration or respiratory cycle phase. If the full respiratory cycle is captured, every phase of the breathing cycle has a complete set of 3D images that can be analyzed to determine organ position.³

Many methods are used to reduce respiratory motion during radiotherapy: breath-hold techniques, patient positioning, forced shallow breathing and respiratory gating. For example, changing patient position from supine to prone results in a caudal shift of abdominal organs via increasing thoracic wall pressure thereby reducing respiratory motion.² In veterinary medicine, cone-beam computed tomography was used to characterize daily urinary bladder variations in dorsal, sternal and lateral recumbency during radiotherapy for canine bladder cancer and for evaluation of canine prostatic intrafractional displacement.^{4,5} Other studies evaluating changes in organ position in dorsal versus ventral recumbency, as well as during ventilation versus apnea are lacking in veterinary medicine.

The goal of this study was to quantify respiratory-induced abdominal organ displacement in dorsal and ventral recumbency in mechanically-ventilated dogs using 4D 64-MDCT. We hypothesized that a statistically significant difference in respiratory induced organ displacement would be found between dorsal and ventral recumbency position, with ventral recumbency position exhibiting less displacement for diagnostic and treatment planning purposes.

Materials and Methods

Five normal 1-year-old Beagle dogs with a mean weight of 11 ± 0.5 kg underwent 4D 64-MDCT (GE LightSpeed, GE, Waukesha, WI, USA). General anesthesia was induced with propofol and maintained with isoflurane in 100% oxygen administered via orotracheal tube. End-tidal carbon dioxide levels were maintained between 35–45 mm Hg using a mechanical ventilator. Periods of apnea were intentionally delivered by increasing the respiratory rate or tidal volume to achieve end-tidal carbon dioxide levels of approximately 30 mm Hg. The dogs underwent a total of four CT exams, two in dorsal and two in ventral recumbency. All exams were acquired in cranial to caudal direction from the caudal aspect of the heart to the pelvic inlet. For each recumbency, we first performed a baseline 3D–apneic exam helical exam of the abdomen during induced apnea. Second, we performed a 4D–ventilated exam acquiring repeated images of the same segment of the abdomen for a time interval greater than an entire respiratory cycle to evaluate displacement due to respiration as a function of time. The exam parameters for the 4D–ventilated exams were 120 kV, 40 mA, 5 mm slice thickness, axial scanning mode, pitch of 0.98 and 1-second tube rotation time. The 4cm wide detector width of the CT scanner was configured to acquire eight contiguous 5mm slices so the abdomen was imaged in multiple acquisitions of 4 cm length in the cranial-to-caudal direction. Over each 4 cm segment a cine exam of 20 tube rotations was acquired during mechanically-induced breathing to include more than one entire breathing cycle. The couch was then translated 4cm and the next segment imaged until the entire abdomen was completely examined (Figure 1). The elapsed time between the 3D–apneic exam and the 4D–ventilated exam was approximately 6 minutes, the time required for resumption of ventilation and image reconstruction from the 3D–apneic exam. Lacking a gating signal of the respiratory cycle, the images from the cine exams were manually segmented using commercial imaging software (OsiriX 64-bit, Pixmeo, Geneva, Switzerland) to form 20 complete anatomic volumes of the abdomen of each dog and recumbency throughout the respiratory cycle.

Using dedicated radiation therapy treatment planning workstations (Pinnacle, Philips Radiation Oncology Systems, Fitchburg, WI, USA and Eclipse, Varian Medical Systems, Palo Alto, CA, USA), the liver, pancreas, both kidneys, both medial iliac lymph nodes and urinary bladder were delineated in each slice of the dorsal and ventral recumbent 3D–apneic CT exams for each dog. Image registration of the volumetric CT data sets generated from the 4D–ventilated exam to the 3D–apneic exam was performed using the same dedicated radiation therapy planning stations. Since the data sets were acquired simultaneously they shared the same DICOM coordinates and were registered using these common coordinates. The data sets were then inspected to ensure that at the level of the diaphragm, the vertebral column showed no displacement between the data sets. The

maximal degree of displacement of each organ on the 4D-ventilated exam relative to the 3D-apneic exam was measured in centimeters (cm). Displacement was defined as any perception in change in organ contour between the 4D-ventilated exam and 3D-apneic exam. Organ displacement was measured in dorsal-to-ventral (DV) and right-to-left (RL) directions using the original transverse image plane and in cranial-to-caudal (CC) direction using images reconstructed in the dorsal plane. We calculated any displacement that was visible, which in this study was as small as 0.6 mm. For all measurements, a single reference point was determined to be in the center of the organ. Then, for each transverse slice, a cursor was placed between the edge of the contour of the organ in the ventilated exam and the edge of the contour of the organ in the apnea exam, where this difference was maximal, in the x (RL direction) and y (DV direction) coordinates of the organ taking the reference point as standard (Figure 2). Likewise for CC direction measurement the cursor was placed in the y coordinate in the dorsal plane images between the contour of the organ in the 4D-ventilated exam and in the 3D-apnea exam where displacement was maximal. Displacement of the spinal cord was calculated by measuring displacement of the vertebral body. It was not possible to measure displacement of the spinal cord and skin in the craniocaudal direction so these measurements were not performed. Statistical analysis was performed using commercial software (GraphPad Prism, Graph Pad Software Inc., La Jolla, CA, USA). The data was tested for normal distribution using the D'Agostino and Pearson normality test. Since the data was not normally distributed, a Wilcoxon signed rank test was used to compare organ displacement between dorsal and ventral recumbency positions among the 3 above described directions. A P-value < 0.05 was considered statistically significant.

Results

The results for organ displacement during the 4D-ventilated exam are displayed in tables 1–9. The maximum displacement for liver was 4.0 cm in DV direction in dorsal recumbency. Ventral recumbency exhibited statistically significant less displacement in the RL direction ($P = 0.0099$) compared to dorsal recumbency. The minimum frequency of displacement was 79/100 for ventral recumbency in the RL direction, and the maximum was 96/100 for ventral recumbency in DV (Table 1). Examples of displacement are shown in Figures 3a and 3b.

For the right kidney, dorsal recumbency resulted in significantly less DV ($P = 0.0005$) and RL ($P = 0.0371$) displacement compared to ventral recumbency (Table 2, Figure 4a). The maximum displacement was 1.2 cm in the RL direction in ventral recumbency. For the left kidney, dorsal recumbency showed statistically significant less DV and RL displacement ($P < 0.0001$ and < 0.0001 respectively) and ventral recumbency showed significantly less CC displacement ($P = 0.0134$). The maximum displacement was 0.97 cm in the DV direction in dorsal recumbency (Table 3, Figure 4b).

For right medial iliac lymph node, dorsal recumbency showed no DV and RL displacement compared to ventral recumbency, the difference being statistically significant for the DV direction only ($P = 0.0156$). No CC displacement was detected for either recumbency (Table 4, Figure 5). Similarly, for the left medial iliac lymph node no CC displacement was detected for both recumbency and dorsal recumbency showed no DV and RL displacement, this being statistically significant from displacement in ventral recumbency ($P < 0.0001$ and

< 0.0001 respectively). In ventral recumbency, displacement was higher compared to the right medial iliac lymph node (Table 5).

For the spinal cord, ventral recumbency exhibited statistically significantly less displacement in the DV direction ($P < 0.0001$), however it occurred more frequently in this position. The maximum displacement noted in dorsal recumbency although statistically significant, was only slightly higher compared to ventral. For the RL direction, dorsal recumbency showed significantly less displacement, which was near statistically significant ($P = 0.0593$). The maximum overall displacement was 0.96 cm in the RL direction in ventral recumbency (Table 6).

For the skin, the ventral recumbency exhibited significantly less displacement in the DV and RL directions and this was statistically significant ($P < 0.0001$ and 0.0029 respectively). Maximum displacement for skin was 0.57 cm in the RL direction in dorsal recumbency (Table 7). For pancreas, dorsal recumbency exhibited statistically significantly less displacement in all directions compared to ventral recumbency ($P = 0.0078$, $P = 0.0005$ and $P = 0.0005$ for DV, CC and RL respectively). The maximum displacement was 1.33 cm in the RL direction in dorsal recumbency (Table 8). For the urinary bladder, ventral recumbency exhibited statistically significant less RL displacement ($P < 0.0001$) with displacement present in only 9 data sets compared to 41 data sets affected with displacement in dorsal recumbency. There was no CC displacement. The maximum displacement was 0.57 cm in the RL direction in dorsal recumbency (Table 9).

Discussion

In the present study we aimed to quantify the degree of abdominal structure displacement during mechanical ventilation in ventral and dorsal recumbency using 4D computed tomography since this type of ventilation is commonly performed in anesthetized animals undergoing CT or radiation therapy. Conventional 3D–apneic exams were used as a reference for organ displacement. Our methodology for measuring abdominal structure displacement was similar to previous human studies evaluating organ displacement and to a recent canine study evaluating intrafractional motion of the prostate.^{2,3,5,6} Several human studies found that abdominal organs moved and changed shapes in a multitude of directions and in an unpredictable way among the different recumbency positions and directions evaluated.⁶ We found similar results in the present study as the displacement of abdominal organs among the different directions varied. Although overall canine abdominal organs displacement for both dorsal and ventral recumbences was less than 1 cm for most organs, for few organs such as liver it was as high as 4 cm, similar to results in humans. The effect of this degree of displacement on the diagnostic value of 3D CT exams has not been specifically evaluated in the veterinary literature, but impairment of depiction of the hepatic anatomy is implied if breath hold is not achieved during image acquisition. This may be especially applicable for studies in which higher detail is needed or where it is imperative to have pre-contrast images matching post-contrast images such as for vascular studies considering the higher degree of displacement that was found for the liver, an organ commonly evaluated in vascular studies. Furthermore, this degree of displacement likely has

a major impact for radiation therapy purposes as organ displacement of > 0.5 cm is considered clinically significant.^{5,7,8}

Liver displacement was expected since the liver is adjacent to the diaphragm and therefore is subject to largest movement with respiration. Similarly, human organs in the upper abdomen such as liver, kidneys and spleen move significantly with respiration.³ In the present study, the majority of segmental exams demonstrated liver displacement, with a minimum of 79% and a maximum of 96% of the data sets having some degree of displacement. Ventral recumbency exhibited the least amount of RL liver displacement compared to dorsal recumbency and this was statistically significant. Similar to humans, we found a minimum liver displacement of 0 cm and maximal of 4 cm for dorsal recumbency. In humans, overall liver displacement was reduced in the prone position compared to supine, attributable to restrained diaphragm movement in the prone position and this position has been suggested for hepatic radiotherapy.² Human organ displacements of liver, spleen and kidneys were broadly distributed among the patient population ranging from 0 to 2.7 cm.³ In another study, liver displacement in humans showed a range of 0.5 to 4.0 cm.⁹

For the kidneys, dorsal recumbency showed the least amount of displacement for all directions for the right kidney, and the least frequency of DV and RL displacement for the left kidney. Therefore, it may be recommended to exam patients in dorsal recumbency to avoid kidney displacement during radiotherapy or imaging of these organs. The degree of kidney displacement in this study was similar to previous human studies evaluating abdominal organ motion using 4D computed tomography where the kidneys moved anteriorly on inspiration from less than 0.1 cm to over 1.4 cm, with an average left kidney displacement of 1.1 cm in the superior-inferior direction, 0.4 cm in the anterior-posterior direction and 0.17 cm in the RL direction, and an average right kidney displacement of 1.3 cm, 0.61 cm and 0.14 cm, respectively.³ In a separate human study measuring kidney displacement in 10 patients, the average left kidney displacement was 1.6 cm in the superior-inferior direction, 0.03 cm in the anterior-posterior direction and 0.12 cm in the RL direction. Right kidney displacement was 1.8 cm, 0.29 cm and 0.08 cm in the superior-inferior, anterior-posterior and RL directions, respectively.¹⁰ Although the degree of kidney displacement in our study is similar to humans, the canine kidneys exhibited much less CC displacement compared to the other two directions which contrasts with humans where CC movement was the major determinant of the overall movement of both kidneys.²

Overall displacement for the medial iliac lymph nodes was mild with no displacement detected in any direction for either lymph in dorsal recumbency, making this position preferred to evaluate these lymph nodes according to our results. Similar studies were not found in the human literature. The maximal spinal cord displacement in our study was 0.96 cm in ventral recumbency for the RL displacement, significantly higher than in dorsal recumbency. For DV direction, although dorsal recumbency showed a higher maximum, it also showed considerably less frequency of displacement therefore it may be advantageous to use the dorsal recumbency for evaluation of the spinal cord. One explanation for the higher displacement of the spinal cord in the ventral recumbency is that there was some degree of flexion of the vertebral column in this position compared to the dorsal position, which allowed the vertebral column to remain in a more straight position. We are currently

unaware of other studies evaluating displacement of the spinal cord between the two different recumbences in human or veterinary medicine literature.

The overall displacement for the skin was considered small in either recumbency or direction, being maximal in the dorsal recumbency in the RL direction at 0.57 cm. A statistically significant difference was found for DV and RL directions indicating the ventral recumbency to have the least displacement with lower median, lower maximal and lower frequency of displacement for both directions. Our results were slightly higher compared to a recent human study evaluating displacement of skin markers during CT of breast cancer where movements of skin markers were approximately 0.12 cm in left-to-right direction, 0.22 cm in anterior-posterior and 0.18 cm in superior-inferior direction for patients with small-sized breasts. A slightly different result was found in the same study for medium and large-sized breasts. The study concluded that intrafractional skin motion of breast tissues was little and could be considered negligible.⁸ As no markers were placed on the skin and marking a position of the spinal cord is also not possible, CC displacement was not assessed for these organs. Where as the other investigated organs have organ borders that are easily identified (example: kidney cranial and caudal pole, lateral and medial margin of renal cortex), this is not given for the skin and spinal cord and concurrent displacement in a different plane than the evaluated one cannot be ruled out (i.e. RL displacement combined with CC displacement), yet we considered the measurable RL and CC displacement as valuable information to be included in the manuscript.

For the pancreas, a statistically significant difference was found for all directions, with dorsal recumbency having overall less displacement. In a human study evaluating pancreatic tumor displacement on a single planning 4D-CT, the mean respiratory displacement of the pancreatic tumor was 1.27 cm in the superior-inferior, 0.94 cm in the left-to-right and 0.55 cm in the anterior-posterior directions.¹¹ The results of our study differ in the superior-inferior direction for which we found considerably less displacement but it is similar in the other directions. In another human study evaluating respiratory movement of upper abdominal organs the mean movement of the pancreas was 1.53 cm, 0.52 cm and 0.97 cm for superior-inferior, lateral and anterior-posterior directions respectively.¹² Some human studies have demonstrated that the magnitude of pancreatic tumor movement is not equal in all directions, and has the largest movement occurring in the superior-inferior direction with the least displacement in the lateral plane.¹² In our study, although the magnitude of movement was also different across the 3 directions, we found the largest displacement in the RL direction, followed by the DV direction. Differences between our results and the human results are expected since we evaluated pancreatic and not pancreatic tumor displacement.

In the present study, increases in the urinary bladder size could have accounted for overall change in position between one recumbency and the other however, the apneic and mechanically-induced breathing exams for each recumbency were performed within six minutes. Therefore, organ displacement due to filling of the urinary bladder is considered unlikely. The urinary bladder exhibited overall infrequent displacement with dorsal recumbency showing more RL displacement. Very few data sets were affected by

displacement in all other directions for both recumbences. Therefore, CT examination in ventral recumbency may be indicated.

Overall, for most canine abdominal organs with exception of liver, urinary bladder and skin, dorsal recumbency provided the least amount of respiratory-induced displacement among the three directions evaluated. In humans, significantly less prostate displacement was seen in dorsal recumbency compared to ventral, possibly due to increased abdominal compression in this position.¹³ In a recent canine study of prostate intrafractional motion, patients were placed in dorsal recumbency to minimize the impact of slow bladder filling.⁵ For imaging diagnosis, it could be advantageous to exam canine patients in dorsal recumbency since this position provided the least respiratory-induced displacement overall. However, comparison of dorsal with ventral recumbency for changes in organ shape, location and diagnostic quality needs to be evaluated in future studies using clinical patients as it was not evaluated in the present study.

This study had several limitations. Four-dimensional CT was performed without respiratory gating so it is not possible to determine the exact respiratory cycle phase in which maximal organ displacement was measured beyond inspection of the images. This could explain, at least in part, the high variability when comparing the same recumbency and same direction of movement across the different data sets. Although respiratory gating was not applied, a full respiratory cycle was recorded at each location during the 4D–ventilated exam. Therefore, all phases of respiration were accounted for in organ displacement calculations. Further, several human studies using respiratory gating technology show similar variability in the degree and direction of organ displacement.^{6,12} Future studies implementing respiratory gating technology may provide additional or more accurate information about organ displacement. The slice thickness of 5 mm used in this study could have increased volume averaging artifact and resulted in visible stair-step artifacts on the reformat images, which could have affected the CC displacement measured on dorsal plane images. However, due to the 4cm detector width of the CT machine, the configuration of the detectors and the large amount of exams performed in this study, thinner slices were not feasible. To make measurements more accurate in this plane, the 4D–ventilated exams were directly compared to the 3D–apnea exams in the fusion mode. Thus, organ displacement, if truly present, could be seen when moving from the exam under apnea to the ventilated exam. Further, we evaluated the apneic studies separately for organ contours; organ contours from transverse plane images matched those on the dorsal plane with very minimal distortion. Finally, despite the slice thickness our results were similar to human studies. Although every effort was made to outline the organs consistently and correctly, significant operator judgment was required in the interpretation of the CT exams specially when contouring the pancreas. This could have lead to some degree of false interpretation of organ displacement. This uncertainty in the volume delineated is inherent to the contouring process, especially on non-contrast studies, and is also reported in the human literature.^{14–17} Reasons for this uncertainty can include partial volume averaging, poorly differentiated anatomy and intra- and inter-operator variations.¹⁴ Finally, we only evaluated dogs of the same breed and similar in size and weight. Dogs of different body conformation, size and weight and especially deep-chested dogs may have different degrees of respiratory motion when placed in dorsal versus ventral recumbency. Further studies are needed to confirm our results as

well as studies evaluating a larger sample size and dogs of different body conformation and weight.

In conclusion, respiratory-induced displacement of canine abdominal organs in dorsal or ventral recumbency during mechanical ventilation was not predictable and showed large variability in the three different directions evaluated. Although displacements were often less than 1 cm, they can be as high as 4 cm. For most canine abdominal organs, dorsal recumbency resulted in the least displacement among all directions evaluated except for liver and urinary bladder. For liver, a large variability among the different directions was found although ventral recumbency exhibited less displacement. For the urinary bladder, ventral recumbency also provided less displacement. It may be advantageous to choose the recumbency according to the specific organ in treatment or under diagnostic investigation when using slower CT machines or during vascular diagnostic studies. Overall dorsal recumbency may be preferred when the entire abdomen is used, but for liver and urinary bladder ventral recumbency may be preferred when respiration cannot be controlled. Other factors need to be accounted for such as ease of patient positioning which may be different in dogs of different body conformation. Future studies using clinical patients undergoing diagnostic or radiation therapy planning exams are warranted in order to confirm our findings.

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Figure 1.

An illustration of the CT exam acquisition process for a study dog in ventral recumbency using a multi-detector row CT scanner. The scanner is operated in cine mode acquiring 20 images for each of the eight adjacent 5mm image reconstructions at each 4cm couch interval for a time interval longer than one respiratory cycle. The couch is then translated for each of the seven couch positions from the cranial to caudal direction. A full 3D–apnea exam of the abdomen throughout the breathing cycle was reconstructed by manually selecting 8 adjacent images from each couch position throughout the breathing cycle.

Figure 2.

Demonstration of how measurements were performed: 3D–apnea exam in dorsal recumbency with contoured organs (arrows) and overlaid 4D–ventilated exam in the transverse plane using image fusion demonstrating the reference point in the center of the liver and the y and x coordinates (arrows). The cursor for measurements in the DV direction (following the y coordinate as reference) and RL direction (following the x coordinate as reference) is demonstrated at the edge of the liver. Measurements in CC direction were performed similarly in the dorsal plane following the y coordinate.

Figure 3.

Display of the 3D–apnea exam with contoured organs (arrows) and overlaid 4D–ventilated exam (not contoured) in the transverse plane using image fusion in ventral (A) and dorsal (B) recumbency positions. Maximal liver displacement in the dorsal-to-ventral direction (white arrow) was 0.39 cm in ventral recumbency (A), compared to 1.43 cm in dorsal recumbency (B). The ventral recumbency position had overall less displacement for liver compared to dorsal recumbency.

Figure 4.

Display of the 3D–apnea exam with contoured organs and overlaid 4D–ventilated exam (not contoured) in the transverse plane using image fusion. In dorsal recumbency position (A) no displacement in dorsal-to-ventral or right-to-left directions is evident for left (white arrow) or right (black arrow) kidney. In ventral recumbency (B) displacement of the left kidney is seen in the dorsal-to-ventral and right-to-left directions.

Figure 5.

Display of the 3D–apnea exam with contoured organs and overlaid 4D–ventilated exam (not contoured) in the transverse plane using image fusion. In dorsal recumbency position (A) no displacement is evident for the left or right medial iliac lymph nodes. In ventral recumbency (B) displacement of the left medial iliac lymph node is seen in the dorsal-to-ventral direction (white arrow).

Table 1

Displacement of Liver in 4D Ventilated Compared to 3D Apneic Exams in 5 Dogs

	DV* direction		CC† direction		RL‡ direction	
	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§
Median (cm)	0.43	0.38	0.41	0.32	0.28	0.35
Minimum (cm)	0	0	0	0	0	0
Maximum (cm)	2.26	4.0	1.79	1.44	2.36	3.4
95% CI of median	0.34 – 0.59	0.27 – 0.53	0.31 – 0.46	0.3 – 0.35	0.22 – 0.34	0.32 – 0.53
P-value	0.7183		0.1294		0.0099	
Freq. of displacement	96%	87%	85%	86%	79%	87%
Total number of data sets (5 dogs segmented in 20)	100	100	100	100	100	100

* Dorsal-to-ventral,

† Cranio-caudal,

‡ Right-to-left,

§ Recumbency

Table 2

Displacement of Right Kidney in 4D Ventilated Compared to 3D Apneic Exams in 5 Dogs

	DV* direction		CC† direction		RL‡ direction	
	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§
Median (cm)	0.15	0	0	0	0.15	0
Minimum (cm)	0	0	0	0	0	0
Maximum (cm)	0.72	0.5	0.86	0.49	1.2	0.78
95% CI of median	0 – 0.22	0 – 0	0 – 0	0 – 0	0 – 0.22	0 – 0
P-value	0.0005		0.4961		0.0371	
Frequency of displacement	58%	26%	6%	4%	60%	23%
Total number of data sets (5 dogs segmented in 20)	100	100	100	100	100	100

* Dorsal-to-ventral,

† Cranio-caudal,

‡ Right-to-left,

§ Recumbency

Table 3

Displacement of Left Kidney in 4D Ventilated Compared to 3D Apneic Exams in 5 Dogs

	DV* direction		CC† direction		RL‡ direction	
	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§
Median (cm)	0.15	0	0	0	0.18	0
Minimum (cm)	0	0	0	0	0	0
Maximum (cm)	0.57	0.97	0.66	0.73	0.82	0.95
95% CI of median	0.13 – 0.17	0 – 0	0 – 0	0 – 0.29	0.15 – 0.24	0 – 0
P-value	< 0.0001		0.0134		< 0.0001	
Frequency of displacement	64%	17%	31%	45%	69%	15%
Total number of data sets (5 dogs segmented in 20)	100	100	100	100	100	100

* Dorsal-to-ventral,

† Cranio-caudal,

‡ Right-to-left,

§ Recumbency

Displacement of Right Medial Iliac Lymph Node in 4D Ventilated Compared to 3D Apneic Exams in 5 dogs

Table 4

	DV* direction		CC† direction		RL‡ direction	
	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§
Median (cm)	0	0	0	0	0	0
Minimum (cm)	0	0	0	0	0	0
Maximum (cm)	0.25	0	0	0	0.12	0
95% CI of median	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
P-value	0.0156		-		0.25	
Frequency of displacement	7%	0%	0%	0%	3%	0%
Total number of data sets (5 dogs segmented in 20)	100	100	100	100	100	100

* Dorsal-to-ventral,

† Cranio-caudal,

‡ Right-to-left,

§ Recumbency

Displacement of Left Medial Iliac Lymph Node in 4D Ventilated Compared to 3D Apneic Exams in 5 dogs

Table 5

	DV* direction		CC† direction		RL‡ direction	
	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§
Median (cm)	0	0	0	0	0	0
Minimum (cm)	0	0	0	0	0	0
Maximum (cm)	0.38	0	0	0	0.44	0
95% CI of median	0 – 0	0 – 0	0 – 0	0 – 0	0 – 0	0 – 0
P-value	< 0.0001		-		< 0.0001	
Frequency of displacement	39%	0%	0%	0%	33%	0%
Total number of data sets (5 dogs segmented in 20)	100	100	100	100	100	100

* Dorsal-to-ventral,

† Cranio-caudal,

‡ Right-to-left,

§ Recumbency

Table 6
Displacement of Spinal Cord in 4D Ventilated Compared to 3D Apneic Exams in 5 dogs

	DV* direction		RL‡ direction	
	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§
Median (cm)	0.15	0	0.03	0.09
Minimum (cm)	0	0	0	0
Maximum (cm)	0.22	0.25	0.96	0.2
95% CI of median	0.14–0.16	0–0.1	0–0.08	0–0.1
P-value	< 0.0001		0.0593	
Frequency of displacement	83%	47%	50%	60%
Total number of data sets (5 dogs segmented in 20)	100	100	100	100

* Dorsal-to-ventral,

‡ Cranio-caudal,

§ Right-to-left,

§ Recumbency

Table 7
Displacement of Skin in 4D Ventilated Compared to 3D Apneic Exams in 5 dogs

	DV* direction		RL‡ direction	
	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§
Median (cm)	0	0	0	0
Minimum (cm)	0	0	0	0
Maximum (cm)	0.22	0.45	0.27	0.57
95% CI of median	0 - 0	0 - 0.14	0 - 0	0 - 0.02
P-value	< 0.0001		0.0029	
Frequency of displacement	26%	44%	38%	40%
Total number of data sets (5 dogs segmented in 20)	100	100	100	100

* Dorsal-to-ventral,

‡ Cranio-caudal,

§ Right-to-left,

§ Recumbency

Table 8

Displacement of Pancreas in 4D Ventilated Compared to 3D Apneic Exams in 5 dogs

	DV [*] direction		CC [†] direction		RL [‡] direction	
	Ventral R [§]	Dorsal R [§]	Ventral R [§]	Dorsal R [§]	Ventral R [§]	Dorsal R [§]
Median (cm)	0	0	0	0	0.18	0
Minimum (cm)	0	0	0	0	0	0
Maximum (cm)	0.48	0.66	0.32	0	0.84	1.33
95% CI of median	0 – 0	0 – 0	0 – 0	0 – 0	0 – 0.18	0 – 0.12
P-value	0.0078		0.0005		0.0005	
Frequency of displacement	19%	2%	8%	0%	60%	40%
Total number of data sets (5 dogs segmented in 20)	100	100	100	100	100	100

* Dorsal-to-ventral,

† Cranio-caudal,

‡ Right-to-left,

§ Recumbency

Table 9
Displacement of Urinary Bladder in 4D Ventilated Compared to 3D Apneic Exams in 5 dogs

	DV* direction		CC† direction		RL‡ direction	
	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§	Ventral R§	Dorsal R§
Median (cm)	0	0	0	0	0	0
Minimum (cm)	0	0	0	0	0	0
Maximum (cm)	0.21	0.39	0	0	0.52	0.57
95% CI of median	0 – 0	0 – 0	0 – 0	0 – 0	0 – 0	0 – 0.22
P-value	0.1719		-		< 0.0001	
Frequency of displacement	8%	2%	0%	0%	9%	41%
Total number of data sets (5 dogs segmented in 20)	100	100	100	100	100	100

* Dorsal-to-ventral,

† Cranio-caudal,

‡ Right-to-left,

§ Recumbency