JVC Journal of Veterinary Clinics

Original Article

pISSN 1598-298X • eISSN 2384-0749
J Vet Clin 2023;40:104-112
https://doi.org/10.17555/jvc.2023.40.2.104

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Assessment of Abdominal Organs Movement by Respiration Using Computed Tomography in Dogs: A Pitfall for Radiation Therapy

Ah Reum Kim[1,†]
Soyon An[1,†]
Gunha Hwang[1]
Moonyeong Choi[2]
Tae Sung Hwang[1,*]
Hee Chun Lee[1,*]

[1]Institute of Animal Medicine, College of Veterinary Medicine, Gyeongsang National University, Jinju 52828, Korea
[2]S Animal Cancer Center, Yangsan 50614, Korea

†Ah Reum Kim and Soyon An contributed equally to this work.

*Correspondence: lhc@gnu.ac.kr (Hee Chun Lee), hwangts@gnu.ac.kr (Tae Sung Hwang)

ORCID
Ah Reum Kim: https://orcid.org/0000-0003-4048-8744
Soyon An: https://orcid.org/0000-0002-9994-8760
Gunha Hwang: https://orcid.org/0000-0002-1805-9137
Moonyeong Choi: https://orcid.org/0000-0001-5069-0714
Tae Sung Hwang: https://orcid.org/0000-0001-6730-6061
Hee Chun Lee: https://orcid.org/0000-0001-5936-9118

Abstract The change in the position of the abdominal organs due to movement by respiration is one of the reasons behind inaccurate irradiation of organs during radiotherapy (RT). Although studies in human medicine have revealed on the respiratory movements of abdominal organs, there is little information and no reference data for dogs. The purpose of this study was to establish the reference values of abdominal organs movement in various postures using computed tomography (CT), and to compare the movements of organs between dorsal recumbency and ventral, right and left lateral recumbency during respiration. CT images for kidney, adrenal gland, medial iliac lymph node, urinary bladder, gallbladder, liver, stomach, and thoracic and lumbar vertebral body of five beagle dogs were acquired. The movements of organs were evaluated by comparing the end-expiratory and end-inspiratory images. Movements of the organs were evaluated by dividing it into right-to-left, dorsal-to-ventral, and cranial-to-caudal directions. The movements of abdominal organs according to the change in postures and respiration were establish. The movement of the bilateral organs was the least when the organs were in the downward position ($p < 0.017$). The movement of cranial-to-caudal direction was greater than the movement of the other directions in most of the organs. Data obtained in this study may be useful in selecting the appropriate posture that can reduce the movements of organs to be treated with RT, and the data could be useful for setting the planning target volume to consider the movements of the abdominal organs by respiration.

Key words canine, respiration, abdominal organs movement, posture, radiation therapy.

Received January 27, 2023 / Revised March 13, 2023 / Accepted March 20, 2023

Introduction

The abdominal organs demonstrate movement due to various causes and respiration-related movements can be divided into interfractional and intrafractional movements (1,10,22). Interfractional motion is the abdominal organ movement caused by daily different filling degrees of organs, including different filling degrees of the urine and feces in the urinary bladder (UB) and intestine, respectively that may change abdominal organ position (1,10,22). The organ movement may be induced by the tissue change after radiation therapy, weight gain or loss, or an increase in the mass size due to tumor progression (1,10,22). Intrafractional motion refers to the organ movement caused by the cardiac cycle, peristaltic movement of the intestine, and movement of organs by respiration (1,10,22). In these movements, respiration has an important effect on the movement of the abdominal organs (4,10). When the position of the organs changes due to the movement of the abdominal organs by respiration, the target tumor cannot be irradiated with an accurate and higher dose of radiation during radiation therapy, and the adjacent important normal tissue remains as improperly irradiated (2,7,18,20). Exposure of the normal parenchymal tissues to radiation causes the side effects such as alveolar infiltration, symptomatic fibrosis, and pneumonitis in the lungs (6). Diarrhea, bloody discharge, and perforation may arise in the gastrointestinal tract, and pollakiuria, dysuria, hematuria, and contracted bladder may occur in the urinary tract (6).

Studies on organ movements have been reported in humans based on ultrasound, fluoroscopy, magnetic resonance imaging, computed tomography (CT), and scintillation cameras (8,18,25,27). The evaluation of organ motion using ultrasonography involves disadvantages such as low reproducibility and artifacts due to gas in the intestine (10). The assessment of the organ movement through fluoroscopy involves disadvantages such as overestimation of the mobility and setting of a large target volume (15,22). CT-based evaluation of the movement is advantageous concerning that the important tissues could be confirmed and the amount of radiation exposure to normal organs could be minimized by reducing the overestimation of the movement, unlike fluoroscopy (15,22).

In veterinary medicine, there exists a study on respiratory movements of the abdominal organs in the ventral and dorsal postures, but there are no studies on respiratory abdominal organ movements in various postures. This study aimed to identify the degree of the abdominal organ movements by respiration in ventral, dorsal, right (Rt.) lateral, and left (Lt.) lateral recumbency using CT scans. Also, by assessing the difference in the degrees of organ mobility by respiration between ventral recumbency that had good posture reproducibility and other recumbency, the suitable posture for radiotherapy of abdominal organs was identified.

Materials and Methods

Preparation and general anesthesia of the experimental animals

All procedures were approved by the Institutional Animal Care and Use Committee at Gyeongsang National University and the dogs were cared for according to the Guidelines for Animal Experiments (GNU-200916-D0063) of Gyeongsang National University. Five healthy beagle dogs (mean weight 10.6 kg, range 8.9-12.3 kg; mean age 6 years; five castrated males) were used in this study. They were screened for evidence of respiratory disease and abdominal organ disease using physical examinations, thoracic and abdominal radiography (Regius model 190®, KONICA Minolta, Japan), and abdominal ultrasonography (Arietta70, Hitach Aloka Medical, Tokyo, Japan). For reducing interfractional motion, the five dogs were kept in a fasting state for 24 hours and the urine volume in UB was unified to 4 mL/kg using a 8Fr urinary catheter (Sewoon Medical, Cheonan, Korea). All the dogs were premedicated with glycopyrrolate 0.01 mg/kg, SC (Myungmoon Pharm, Seoul, Korea). Anesthesia was induced with alfaxalone 2 mg/kg, IV (Careside, Sungnam, Korea) through a 24-gauge intravenous catheter in the cephalic vein. General anesthesia was maintained with isoflurane (Hana Pharm, Seoul, Korea) in oxygen (2 L/min) via endotracheal intubation.

Protocols of CT

The examinations were performed on a 160 multislice helical CT scanner (Aquilion Lightning 160®, Canon Medical Systems, Japan). The scanning parameters of the CT were as follows: 1 mm collimation, 250 mAs, 120 kVp, 0.75 sec rotation time, and pitch factor of 1.475. The CT scans were performed in the ventral, the right lateral, left lateral, and dorsal recumbency at the end-inspiration and the end-expiration, respectively. CT images were reconstructed using soft tissue reconstruction algorithm and soft tissue window (window level, 40; window width, 400).

End-inspiration was created by manually compressing the reservoir bag of the anesthetic machine to achieve an airway pressure of 15 cmH_2O; the pressure was maintained with breath-holding. End-expiration was created by hyperventilation; the dogs were induced apnea and an airway pressure of 0 cmH_2O was created. After each posture and breathing condition were prepared, the CT examinations were performed from the caudal aspect of the heart to the caudal aspect of the pelvis in the cranial to the caudal direction in each recumbency.

Image analysis

All CT images were analyzed through a DICOM viewer (RadiAnt DICOM Viewer, version 2020.2; Medixant Inc., Poland) and the images were evaluated by converting axial images into sagittal and coronal images using the multiplanar reconstructions (MPR) function with the DICOM viewer. The evaluated organs were both the kidneys, both adrenal glands (AG), both the medial iliac lymph nodes (LN), UB, gallbladder (GB), hepatic dome, left hepatic lobe, fundus and pylorus of the stomach, 10th and 13th thoracic (T) vertebral body, and 2nd and 5th lumbar (L) vertebral body.

Abdominal organs movements were evaluated from right-to-left (RL), dorsal-to-ventral (DV), and cranial-to-caudal (CC) direction. RL direction was assessed in the x-coordinates of the axial plane in ventral and dorsal recumbency and y-coordinates of the axial plane in both the lateral recumbency. DV direction was assessed in the x-coordinates of the sagittal plane in all the recumbency and CC direction was evaluated in the y-coordinates of the coronal plane in all the recumbency. To calibrate the degree of coordinate change to mm, after the measurement of the extent of coordinate changes at the length corresponding to 1 cm in the DICOM viewer, the identification of one coordinate as 0.05 mm was confirmed.

The difference in the coordinates was measured at the longest short axis and long axis, to assess the maximum movement of each organ. The movement of RL direction, first, in the end-expiratory image at a reference point, led to checking of the coordinates of the maximal left and right side of the organ in the axial plane. Second, in the end-inspiratory image, the coordinates of the maximal left and right sides of the organ at the reference point in the axial plane were identified. Also, the differences in the coordinates of the inspiratory and expiratory image on the left side and the right side in the organ were identified, respectively. The maximum value of the coordinate change was determined to be the degree of movement of the organ. The movement of DV direction led to checking of the coordinates of the maximal dorsal and ventral side of the organ in the sagittal plane and the movement of CC direction led to the identification of the coordinates of the maximal cranial and caudal point of the organ in the coronal plane. The rest of the method was performed similarly as in the RL direction (Fig. 1).

The criteria of kidney and AG were at the renal pelvis level and the caudal vena cava level, respectively. The criteria of medial iliac LN were at the terminal branches of the abdominal aorta. The criteria of UB and GB was at the level which was the short axis and long axis of the longest cross-section and that of the hepatic dome and Lt. hepatic lobe was the uppermost portion of the liver which was attached to the diaphragm by coronary ligament and the long axis of the longest cross-section of the left hepatic lobe, respectively. The criteria of fundus and pylorus of the stomach were at the level at which the gastroesophageal junction ended and the pyloroduodenal junction ended. The criteria of the vertebral

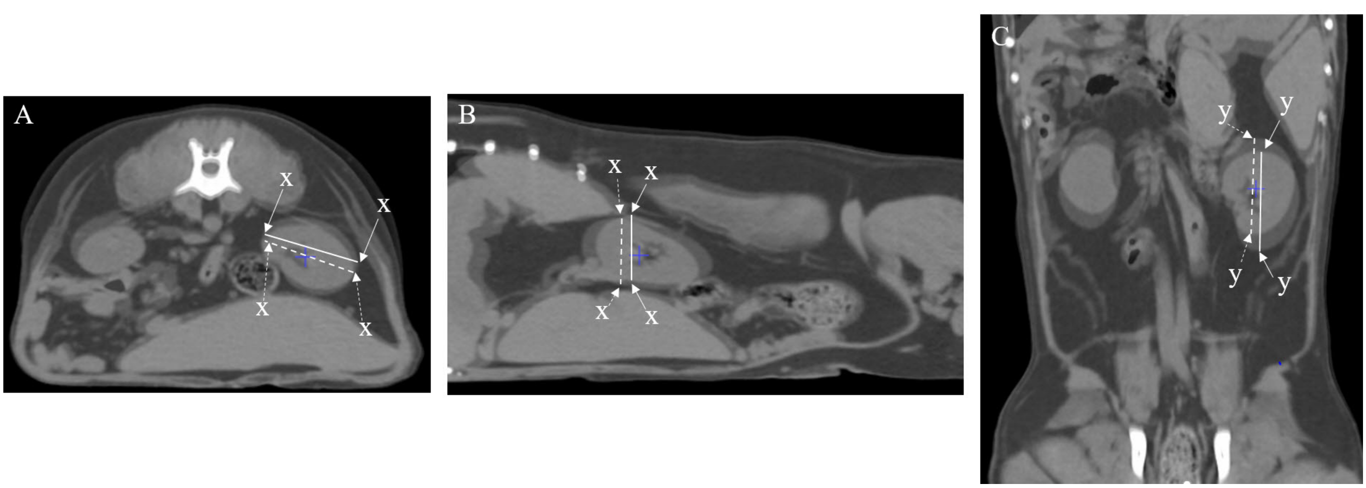

Fig. 1. The difference in the degree of the right-to-left (RL), dorsal-to-ventral (DV), and cranial-to-caudal (CC) movements of the left kidney by respiration in ventral recumbency. The end-inspiratory images (solid line) and end-expiratory images (dotted line) of the left kidney were overlapped to measure RL movement (A) in the axial plane, DV movement (B) in the sagittal plane, and CC movement (C) in the coronal plane at a reference point. The coordinates of the maximal left and right side (A), dorsal and ventral side (B), cranial and caudal side (C) of the organ in the end-inspiratory images (solid arrows), and end-expiratory images (dotted arrows) were checked in each plane.

Table 1. Movement of both the kidneys, both the adrenal glands, both the medial iliac lymph node, urinary bladder, gallbladder, hepatic dome, Lt. hepatic lobe, fundus, pylorus, 10th and 13th thoracic, and 2nd and 5th lumbar vertebral bodies between end-expiration and end-inspiration in various recumbency

	Right to Left direction (mean ± SD, mm)					Dorsal to ventral direction (mean ± SD, mm)					Cranial to caudal direction (mean ± SD, mm)				
	Ventral R	Dorsal R	Rt. lateral R	Lt. lateral R	p-value	Ventral R	Dorsal R	Rt. lateral R	Lt. lateral R	p-value	Ventral R	Dorsal R	Rt. lateral R	Lt. lateral R	p-value
Rt. Kidney	1.50 ± 1.58	0.90 ± 0.65	0.60 ± 0.41	1.20 ± 0.57	0.502	3.30 ± 2.53	2.10 ± 1.19	0.70 ± 0.75	3.00 ± 1.00	0.044	11.00 ± 3.88	7.50 ± 1.69	4.10 ± 0.65*	8.80 ± 2.58	0.007
Lt. kidney	2.10 ± 0.65	1.10 ± 0.74	1.60 ± 1.29	0.50 ± 0.35*	0.037	1.00 ± 0.35	1.60 ± 0.82	2.50 ± 0.70	1.70 ± 1.03	0.069	8.90 ± 2.94	7.00 ± 1.87	11.20 ± 1.44	5.60 ± 2.07	0.020
Rt. adrenal gland	1.10 ± 0.41	1.10 ± 0.41	0.70 ± 0.44	1.00 ± 0.61	0.508	0.80 ± 0.44	1.60 ± 0.74	0.70 ± 0.44	1.70 ± 1.03	0.113	6.20 ± 1.64	4.80 ± 0.75	3.90 ± 1.02	6.10 ± 1.24	0.021
Lt. adrenal gland	1.60 ± 1.91	0.40 ± 0.22	0.70 ± 0.27	0.70 ± 0.57	0.233	1.40 ± 0.65	0.80 ± 0.27	0.80 ± 0.83	0.80 ± 0.44	0.371	3.90 ± 0.82	3.30 ± 1.25	4.20 ± 1.09	3.70 ± 0.83	0.259
Rt. medial iliac lymph node	0.40 ± 0.41	0.40 ± 0.22	0.80 ± 0.27	1.00 ± 0.50	0.072	1.60 ± 0.82	0.40 ± 0.41*	0.50 ± 0.00*	0.80 ± 0.27	0.060	1.30 ± 0.75	1.20 ± 0.75	0.70 ± 0.57	1.10 ± 0.82	0.600
Lt. medial iliac lymph node	0.70 ± 0.44	0.30 ± 0.27	1.10 ± 0.82	0.30 ± 0.27	0.039	1.50 ± 0.50	0.40 ± 0.20*	0.60 ± 0.41	0.40 ± 0.65	0.022	1.80 ± 0.90	1.20 ± 0.75	1.10 ± 0.65	0.90 ± 0.65	0.385
Urinary bladder	0.80 ± 0.75	1.10 ± 0.54	1.70 ± 1.39	2.70 ± 1.71	0.163	1.10 ± 0.41	1.80 ± 1.82	1.20 ± 1.15	1.70 ± 1.03	0.825	3.10 ± 1.34	3.30 ± 2.75	2.40 ± 0.41	3.00 ± 1.41	0.914
Gall-bladder	1.70 ± 0.35	2.00 ± 1.54	3.00 ± 2.03	1.50 ± 0.93	0.539	4.70 ± 0.75	2.50 ± 1.17*	6.90 ± 3.38	6.70 ± 1.60	0.010	9.40 ± 1.59	11.50 ± 2.15	10.00 ± 1.06	11.20 ± 3.43	0.526
Hepatic dome	1.40 ± 0.65	3.80 ± 0.83*	1.20 ± 0.75	2.70 ± 1.25	0.009	4.40 ± 2.53	1.40 ± 0.96	2.90 ± 1.38	4.60 ± 0.41	0.016	8.40 ± 1.98	10.70 ± 2.16	11.30 ± 1.30	7.80 ± 1.15	0.027
Lt. hepatic lobe	2.30 ± 1.48	3.50 ± 0.79	1.50 ± 1.27	3.00 ± 2.73	0.203	5.80 ± 2.01	3.30 ± 2.01	5.80 ± 2.07	4.70 ± 1.82	0.167	9.40 ± 2.72	11.00 ± 0.93	11.70 ± 1.60	8.80 ± 2.41	0.135
Fundus	3.00 ± 1.69	1.40 ± 0.74	2.60 ± 2.10	2.30 ± 1.64	0.395	6.30 ± 3.09	1.70 ± 1.03*	4.60 ± 2.72	4.10 ± 1.55	0.049	10.50 ± 3.06	10.00 ± 2.00	13.60 ± 1.98	10.10 ± 2.67	0.107
Pylorus	1.40 ± 0.82	1.90 ± 0.96	1.70 ± 1.98	2.70 ± 1.20	0.332	4.50 ± 2.06	1.00 ± 0.35*	5.00 ± 2.42	6.60 ± 1.38	0.006	10.40 ± 2.32	11.90 ± 1.81	13.00 ± 2.37	14.10 ± 2.85	0.251
10th thoracic vertebral body	0.00 ± 0.00	0.00 ± 0.00	0.80 ± 0.27*	0.80 ± 0.27*	0.010	1.10 ± 0.41	0.00 ± 0.00*	0.10 ± 0.22*	0.30 ± 0.27*	0.030	0.10 ± 0.22	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.392
13th thoracic vertebral body	0.10 ± 0.22	0.00 ± 0.00	0.70 ± 0.27*	0.70 ± 0.27*	0.002	1.30 ± 0.44	0.00 ± 0.00*	0.10 ± 0.22*	0.10 ± 0.22*	0.002	0.10 ± 0.22	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.392
2nd lumbar vertebral body	0.00 ± 0.00	0.00 ± 0.00	0.50 ± 0.00*	0.50 ± 0.35*	0.002	1.70 ± 0.57	0.00 ± 0.00*	0.10 ± 0.22*	0.10 ± 0.22*	0.002	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.00
5th lumbar vertebral body	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.27	0.40 ± 0.41	0.073	1.70 ± 0.57	0.00 ± 0.00*	0.10 ± 0.22*	0.20 ± 0.27*	0.002	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.00

*Significant difference from ventral recumbency, $p < 0.017$ (Mann Whitney U-test). R, recumbency; Rt., right; Lt., left.

body were the midline level of vertebral body.

Statistical analysis

Statistical analysis was performed using the SPSS statistical computer program (SPSS for Windows, Release 25.0, standard version, SPSS Inc., USA). The degree of the abdominal organ movements between the ventral recumbency and dorsal, Rt. lateral, Lt. lateral recumbency were statistically analyzed using the Kruskal-Wallis test. Kruskal-Wallis test was used to compare each group and post-hoc Mann Whitney U-test was used to compare between ventral recumbency and the other recumbency. In the statistical test, a p-value less than 0.05 for the Kruskal-Wallis test and 0.017 for Mann Whitney U-test were considered to indicate a significant difference.

Results

The RL, DV, and CC movements of organs by respiration in various postures and the significance between the ventral recumbency which was the control group, and other recumbency are described in Table 1, Figs. 2, and 3.

Among the movements of the Rt. kidney, the RL, DV, and CC movements were confirmed to be the largest in the ventral recumbency. CC direction movement was the smallest in the Rt. lateral recumbency, and significantly smaller compared to the ventral recumbency.

Among the movements of the Lt. kidney, RL direction movement was smallest in the Lt. lateral recumbency, and significantly smaller compared to the ventral recumbency. There was no significant difference in the DV and CC movement according to the posture. However, DV and CC movements were the maximum in the Rt. lateral recumbency. In both the kidneys, CC movement was the largest of all the direction movements in all postures.

There was no significant difference in the RL, DV, and CC movement of both the AGs in all the postures. In the case of DV movement of the Rt. AG, the movement was great in dorsal and Lt. lateral recumbency. In both the AGs, the CC movement was the largest of all the directions movements in all the postures.

The DV movement of the bilateral medial iliac LNs was significantly greater in the ventral recumbency than in the dorsal recumbency. In the Lt. medial iliac LN, there was no significant difference in the RL movement according to all the postures, but the RL movement was large in the Rt. lateral recumbency.

There were no significant differences in the UB movement in all the directions according to the postures, but the RL

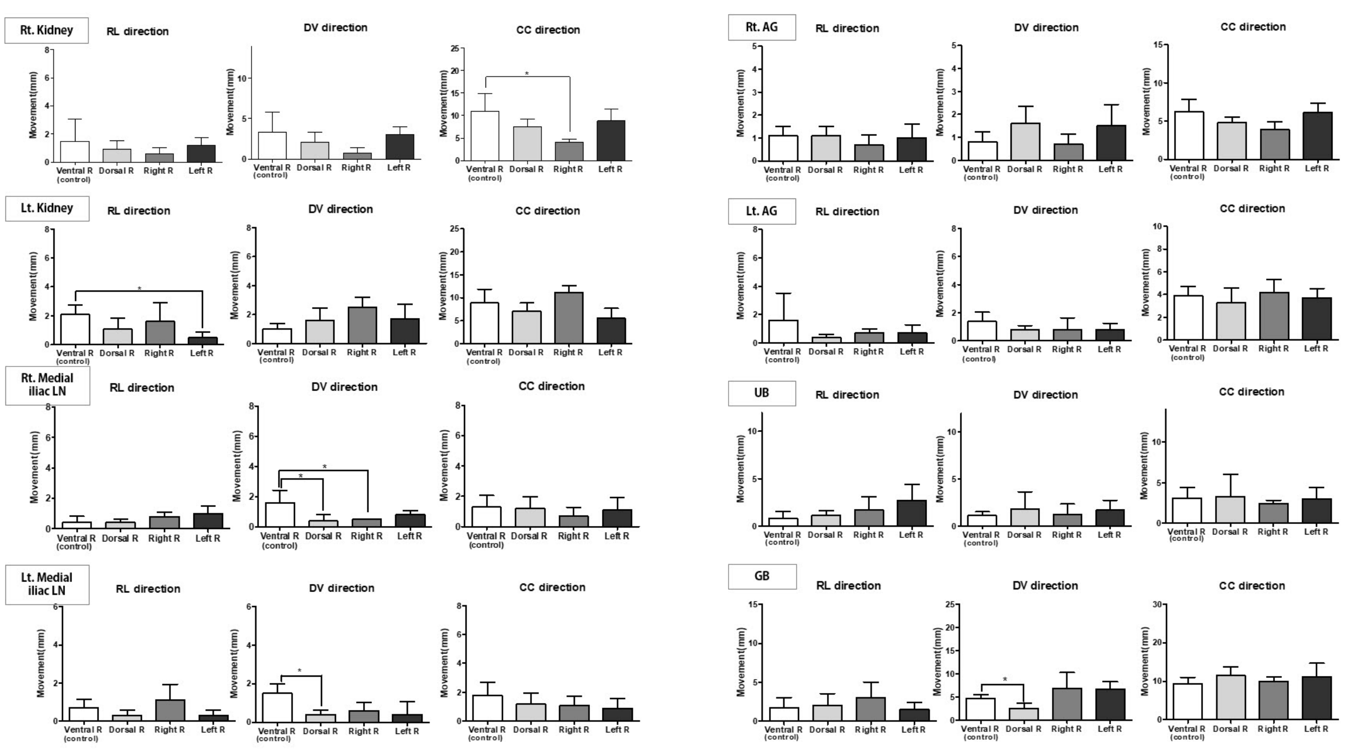

Fig. 2. The significant difference between ventral and other postures about right-to-left, dorsal-to-ventral, and cranial-to-caudal movements of bilateral kidney, bilateral medial iliac lymph nodes, urinary bladder, and gallbladder. Movements of organs by respiration in various postures.

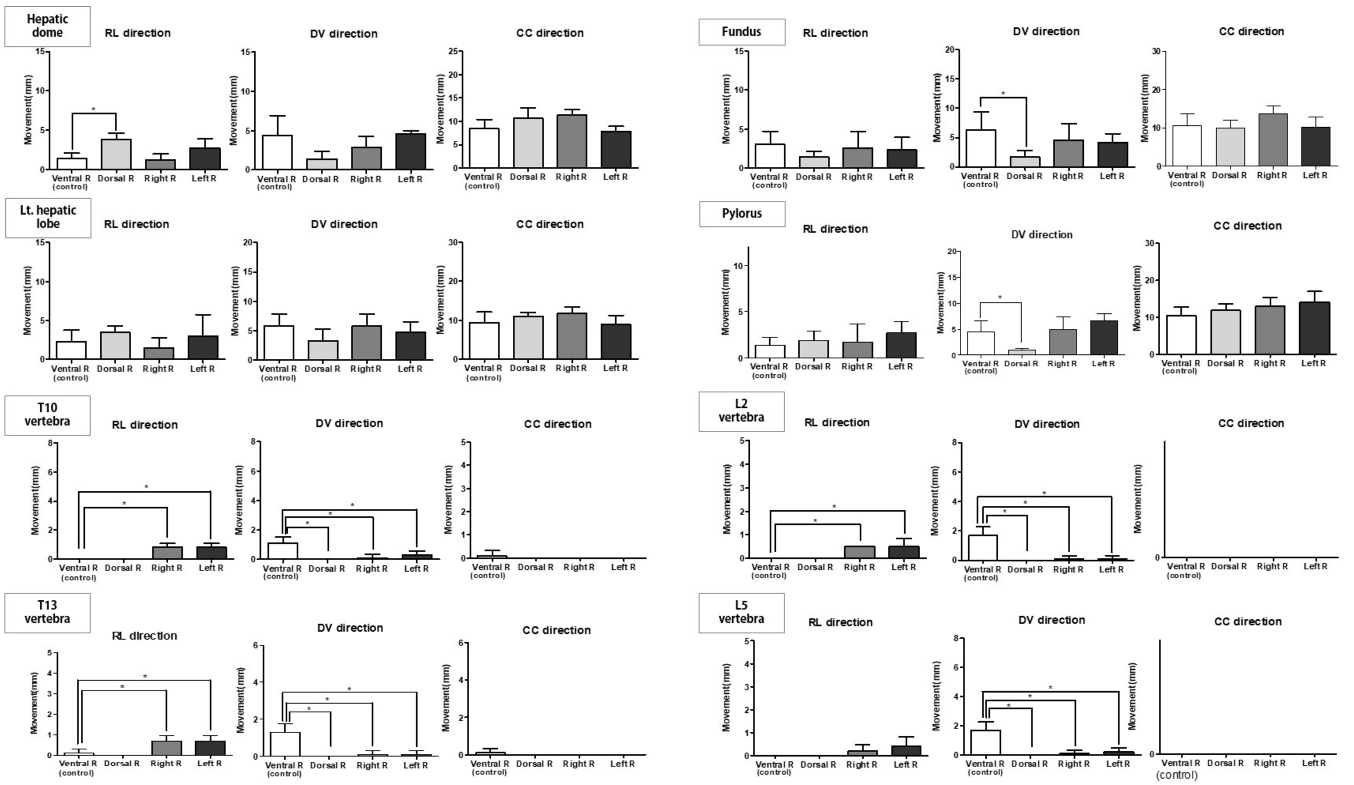

Fig. 3. The significant difference between ventral and other postures about right-to-left, dorsal-to-ventral, and cranial-to-caudal movements of the hepatic dome, left hepatic lobe, fundus, pylorus, T10, T13, L2, and L5 vertebra. Movements of organs by respiration in various postures.

movement was large in the Lt. lateral recumbency.

The DV movement of the GB was significantly smaller in the dorsal recumbency than in the ventral recumbency. There were no significant differences in the RL and CC movements according to the postures. CC movement was the largest of all the movements in all the recumbency.

The RL movement of the hepatic dome was significantly greater in the dorsal recumbency than in the ventral recumbency. There was no significant difference in the RL, DV, and CC movement of the Lt. hepatic lobe in all the postures. CC movement was the largest of all the movements in all the recumbency of the hepatic dome and Lt. hepatic lobe.

The DV movement of the fundus and pylorus was significantly smaller in the dorsal recumbency than in the ventral recumbency. CC movement was the largest of all the movements in all the recumbency.

The RL movement of the T10, T13, and L2 vertebral body was significantly greater in the Rt. and Lt. lateral recumbency than in the ventral recumbency. The DV movement of the T10, T13, L2, and L5 vertebral body was significantly greater in the ventral recumbency than in the other postures.

Discussion

In the present study, it was investigated whether the mobility of abdominal organs by respiration showed a significant difference between the ventral recumbency and dorsal, Rt., and Lt. lateral recumbency. In veterinary medicine, radiation therapy has often been performed in a ventral position in patients with various tumors such as heart base tumor, prostatic carcinoma, hepatocellular carcinoma, and adrenal gland tumor (13,17,19,23). In addition, as the ventral recumbency has good posture reproducibility, a control group has been set to the ventral recumbency (16). In human and veterinary medicine, numerous studies have been conducted on the respiration-induced movement of the abdominal organs using four-dimensional CT and radiation therapy treatment planning workstation in the ventral recumbency and dorsal recumbency during the free-breathing or mechanical ventilation state (4,10). However, in our study, the movement was analyzed by comparing the coordinates after the MPR reconstruction method with DICOM viewer instead of the analysis through the planning workstation. The reason for using such a method was the imperativeness behind the evaluation of the overall maximum movement of organs for radiation therapy; hence, the cross-section with the longest axis of each organ in the axial, sagittal, and coronary plane was evaluated. Next, we tried to evaluate the biggest movement of each organ. As the veterinary study only proceeded in ventral and dorsal positions, we conducted further studies on the movements in Rt. and Lt. lateral recumbency.

In human study, mean movements of Rt. kidney to RL, anterior to posterior (AP), and CC directions were confirmed to be larger in the supine position than in the prone position. The movements of RL and CC directions of Lt. kidney were larger at the prone position and the AP direction was larger at the supine position (10). In the veterinary study, the median movement of both the kidneys to RL, DV, and CC directions was larger in the ventral recumbency position than in the dorsal recumbency position (4). In our study, all the mean movements of the Rt. kidney and the mean RL movements of the Lt. kidney were similar to the movements noted in the veterinary study; however, the DV and CC movement of the Lt. kidney was largest in Rt. lateral recumbency, which was different from the veterinary study (4). In addition, the CC movement of Rt. kidney in Rt. lateral recumbency and the RL movement of Lt. kidney in Lt. lateral recumbency were significantly smaller than the ventral recumbency. While performing radiation therapy, the Rt. lateral recumbency can be useful for reducing the CC movement of the Rt. kidney and the Lt. lateral recumbency can be useful for reducing the RL movement of the Lt. kidney.

Similar studies about the AG movement have not been reported in human and veterinary studies. In humans, the movements of bilateral adrenal tumors by respiration in the supine position were confirmed at RL, AP, and CC directions with 0.27 ± 0.07 cm, 0.31 ± 0.11 cm, and 0.87 ± 0.21 cm, respectively (21). In another human study, the movements of AG in the RL, CC, and AP direction were confirmed to be larger at the prone position when assessing the movements of AG in the supine and prone positions (5). In our study, CC movement was the largest movement of both the adrenal glands in all the positions, which was similar to the results of previous studies (21). In our study, there were no significant differences in all the direction movements of bilateral AGs in all the postures. However, the movements of Rt. AG in all the directions were the least in the Rt. lateral recumbency. The RL and DV movements of the Lt. AG were large in the ventral position. The RL movements of bilateral AG should be reduced because the AG adjoins the abdominal aorta, caudal vena cava, and kidney. Therefore, Rt. lateral recumbency for the Rt. AG and the Lt. lateral recumbency for the Lt. AG, where the RL movement is the smallest can be useful for radiotherapy. The author recommends avoiding ventral position with high movement.

In the veterinary study, when the movements of medial iliac LN by breathing were compared in ventral and dorsal postures, the median movements in all the directions were not confirmed, and the maximum movement of DV and RL on both the LN was confirmed in the ventral posture (4). In our study, the DV movement of the bilateral medial iliac LNs was also significantly greater in the ventral recumbency than in the dorsal recumbency. In the RL movement of the Lt. LN, there was no significant difference according to all the postures, but the RL movement was large in the Rt. lateral recumbency. Dorsal recumbency may be recommended to reduce DV movement of both the medial iliac LN for radiation therapy.

In veterinary medicine, when the UB movement by respiration was compared in ventral and dorsal posture, the median movements in all the directions were not confirmed, and the maximum movement of DV and RL was confirmed in the dorsal posture (4). In our study, there was no significant difference in UB movement between ventral and other recumbency in all the directions; the ventral posture that had good posture reproducibility can be considered to be useful for radiotherapy. The RL movement of UB was large in the Lt. lateral recumbency. Considering the adjacency of UB to the prostate and descending colon, there exists a study in which the lateral posture was good to minimize the irradiation of the adjacent organs; thus, it was thought that the Rt. lateral posture could be more useful for radiation therapy (14).

Similar studies about GB movement were not found in the human and veterinary studies. When evaluating the movement of the GB due to breathing and peristaltic movement in humans, the movements of RL, AP, and superior to inferior (SI) direction were identified with 0.4 ± 0.1 cm, 0.5 ± 0.1 cm, and 0.9 ± 0.4 cm, respectively (12). Our study identified that CC movement was larger than others, and the results were similar to that of the human study (12). The DV movement of GB in dorsal recumbency was significantly smaller than the ventral recumbency, and it is hypothesized that the dorsal recumbency may be useful in reducing DV movement during radiation therapy.

In the human study, the mean movement of the hepatic dome and liver lower tip in all directions was confirmed to be larger in the supine posture (10). In the veterinary study, the median DV and CC movements of the liver were large in the ventral posture and the median RL movement was large in the dorsal posture (4). In our study, there was no significant difference in the DV movement of the hepatic dome and Lt. hepatic lobe. The RL movement of the hepatic dome was confirmed to be larger in the dorsal recumbency than in the ventral recumbency, and no significant difference between the postures was confirmed in the left hepatic lobe. Ventral recumbency can be useful for reducing RL movement of the hepatic dome and for having good posture reproducibility for radiation therapy.

There exist no studies about the movement of fundus and pylorus in the humans and veterinary area. In the human study, the mean movements of the stomach in RL, AP, and CC directions by respiration were confirmed with 1.7 mm, 8.8 mm, and 16.4 mm, respectively (11). Whereas in another human study, the movements of the stomach in each direction were identified with 2.9 ± 1.3 mm, 4.1 ± 1.4 mm, and 10.1 ± 4.5 mm, respectively (24). In our study, the DV movements of the fundus and pylorus confirmed that the dorsal posture was significantly smaller than the ventral posture. The dorsal recumbency can be useful for reducing DV movement of the fundus and pylorus for radiation therapy.

Similar studies about the movement of the vertebral body have not been reported in the humans and veterinary areas. In veterinary medicine, when the movements of the spinal cord by respiration were evaluated in the ventral and dorsal postures, the median RL and DV movements were confirmed to be larger in the ventral posture, and CC movement was not confirmed (4). In the human study, when the movements of the vertebral body by respiration were evaluated at the prone position, the movement of the 7th and 12th thoracic vertebral bodies and 2nd lumbar vertebral body was confirmed to be larger than that of the 3rd and 7th cervical vertebral bodies and sacral vertebral body, and AP motion was larger than RL and CC motions (3). In our study, the DV movements of all the vertebral body in ventral recumbency were larger than the other recumbency. The RL movements of T10, T13, and L2 vertebral bodies in both the lateral recumbency were larger than in the ventral recumbency. Therefore, dorsal recumbency can be useful for reducing DV and RL movements for radiation therapy. However, if the posture reproducibility is not good, the Lt. or Rt. lateral posture can be considered.

While evaluating the direction of RL, DV, and CC in various postures with the largest movement, CC movement was confirmed to be the largest in most of the organs; the movements of most of the organs were confirmed similarly as in the human and veterinary studies (3-5,10-12,21,24). It was identified that the maximum movements changed according to the postures in Rt. medial iliac LN. The RL movement of the vertebral body in the lateral posture was confirmed to be larger and the CC movements of Lt. medial iliac LN were different from the ones reported in human and veterinary studies (3,4,10). In the human study, the different degrees of diaphragm movement and tidal volume change in chest conformation were identified between shallow respiration and deep respiration (26). In the veterinary study, the findings reported that the regional activity of the diaphragm changed depending on the posture (9). Thus, due to differences in breathing conditions and postures, it was considered that there were differences in the movements of some of the abdominal organs between our study and the reported human and veterinary studies.

This study has some limitations. First, the small number of dogs was a limitation of our study which may reflect a type II statistical error. As the results may differ depending on the species or body-weight, additional studies are needed. Second, this study performed CT scan in other postures immediately after CT scan in the ventral recumbency posture. This may have affected the displacement values of the upper abdominal organs due to lung collapse. However, as it was confirmed that the degree of lung collapse was not severe in CT images obtained in other positions, the impact of this on the resulting values is considered to be subtle. Third, when measuring the movement in the RL, DV, and CC directions, the relative movement value between the images of expiration and inspiration was measured. Further studies on absolute movement value in cranial, caudal, right, left, dorsal, and ventral directions between expiration and inspiration are needed. Finally, the end-inspiratory airway pressure was set at 15 cmH_2O in this study. Organ movement can be more influenced by tidal volume than by pressure. Depending on factors such as chronic respiratory disease, obesity, and others, the ventilated tidal volume may vary even when a certain pressure is applied. Therefore, further studies are needed to examine the effects of tidal volume, body weight, and obesity on organ movement.

Bilateral organs had been confirmed to have the least movement when the organ is in a downward position, and in most of the postures, the cranial to caudal movement of most of the organs was confirmed to be greater than in other directions. Through this study, we selected a posture that can reduce organ movement by respiration when performing radiation therapy. The value of movement of abdominal organs according to the change in the postures and respiration was confirmed. When contouring the planning target volume for radiation therapy, these movements of organs should be considered.

Acknowledgements

This work was supported by the Animal Medical Institute of Gyeongsang National University and the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF-2020R1G1A1007886).

Conflicts of Interest

The authors have no conflicting interests.

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