Estimation of time to peak contrast enhancement of the aorta and liver for dual-phase computed tomography on the basis of contrast medium arrival time, injection duration, and injection technique in dogs

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OBJECTIVE
To evaluate the accuracy of estimating time to peak enhancement (TPE) of the aorta and liver parenchyma on the basis of contrast medium arrival time in the aorta, injection duration, and injection technique in dogs.

ANIMALS
18 dogs of specific body weight categories (≥ 2 dogs/category) with no liver abnormalities detected via CT.

PROCEDURES
Dogs were randomly assigned within weight categories to receive contrast medium IV at a fixed injection rate (5 mL/s) or fixed injection duration (20 seconds). Time–contrast attenuation curves were generated from dynamic CT scans acquired at the hepatic hilus. Data collected for contrast medium arrival time and injection duration were used to estimate TPEs of the aorta and liver, and results were compared with the observed TPEs for the aorta and liver.

RESULTS
Contrast medium arrival time, injection duration, and injection technique were significantly associated with observed values for aortic TPE and explained 96.1% of variation in TPE. For the fixed rate technique, the regression equation for estimating aortic TPE was 0.8 X (injection duration + contrast medium arrival time) + 1.6. For the fixed duration technique, the regression equation changed by only the constant (–2.6). However, the hepatic TPE estimated from the 3 predictor variables was not significantly different from the mean of observed TPEs.

CONCLUSIONS AND CLINICAL RELEVANCE
Aortic TPE could be accurately estimated from contrast medium arrival time, injection duration, and injection technique in dogs with apparently healthy livers. The regression equations derived from this relationship can be used to improve the efficiency of dual-phase CT of the liver in dogs. (*Am J Vet Res* 2016;77:1093–1100)

The applications for contrast CT of the abdomen include vascular and parenchymal imaging. Vascular CT imaging has been used for angiographic evaluation of clinically normal dogs and is a useful technique for the diagnosis of congenital vascular malformations such as portosystemic shunts, hepatic arteriovenous fistulas, and malformations of the caudal vena cava.[1–6] More recently, multiple studies[7–9] have been conducted to explore applications for parenchymal CT imaging, particularly of the liver and pancreas in dogs. The advent of fast, multidetector CT technology has enabled acquisition of data pertaining to both arterial and parenchymal phases of contrast enhancement after a single contrast injection. Dual-phase contrast CT of the liver and pancreas in people is performed to increase the sensitivity for lesion detection and to enable characterization of disease.[10–14]

The principal goal of dual-phase CT is to acquire images when optimal contrast resolution of the structure of interest is evident following contrast medium injection.[12] This occurs when there is differential enhancement between the focal lesion and the surrounding parenchyma. When contrast resolution is optimized, the sensitivity increases for detecting focal lesions in organs such as the liver and pancreas.[7–9] Focal hepatic lesions that are hypervascular will increase in conspicuity during the arterial phase be-

ABBREVIATIONS
HU Hounsfield unit
ROI Region of interest
TPE Time to peak enhancement

cause the surrounding hepatic parenchyma will be slower to have contrast enhancement. Subsequent diffuse parenchymal enhancement will render these lesions nonvisible, but other types of lesions that are hypovascular will be more evident during the parenchymal phase.[12,15] The timing of image acquisition following contrast medium injection is therefore of paramount importance when assessing the liver via CT.

The aim of dual-phase CT imaging is to capture peak arterial enhancement during the arterial phase and peak parenchymal enhancement during the hepatic phase. As a result, TPE of the arteries and parenchyma is an important consideration when planning CT scans.[16,17] Operators attempt to synchronize the early and late CT scan with TPE of the arteries and parenchyma, respectively. Achieving an accurate early CT scan that captures peak arterial enhancement is particularly challenging because of the inherently narrow temporal window of peak contrast enhancement.[17]

Various techniques for contrast medium injection and protocols for CT timing exist for dual-phase hepatic CT imaging in veterinary patients; however, the accuracy of these methods has not been objectively measured. A commonly used technique for contrast medium administration is IV injection by hand followed immediately by CT scanning. This technique has been used for angiographic evaluations to characterize normal anatomy and portosystemic shunts but not for dual-phase evaluations of parenchymatous organs.[6,18,19] The main limitation of administering contrast medium by hand is that there is no control over the injection duration, which is one of the most important factors in the calculation of TPE.[17,20–22]

A second contrast injection technique via a fixed injection rate (3 to 5 mL/s) has been used for dual-phase CT scans of the liver and pancreas.[1,9] Likewise, this technique does not take injection duration into account for estimating TPE of the aorta and liver. The technique for achieving a fixed injection rate has been used in conjunction with a test bolus procedure to estimate TPE. The test bolus procedure involves a small dose (eg, 0.5 to 1 mL/kg) of contrast medium administered IV to gauge the timing of enhancement in a subject prior to administration of the diagnostic bolus (2 mL/kg, IV). However, when 2 different volumes of contrast medium are given at the same injection rate, the injection duration is subsequently modified. Therefore, the information provided by the test bolus is considered a poor estimate of TPE but a good estimate of the time required for contrast medium to circulate from the venous injection site to the aorta (contrast medium arrival time).[17]

A third type of technique for contrast medium injection involves a fixed injection duration.[7,8] Contrast medium is administered at a fixed injection duration of 15 to 20 seconds, and the CT scan is started after a fixed delay period. The fixed scan delay for the early and late CT scans is the same for every subject. This technique may result in asynchrony between the CT scan and peak enhancement because of intersubject differences in blood circulatory time and cardiac output. Subjects with low cardiac output caused by cardiac disease or anesthetic depth are expected to have slower circulatory times, resulting in a delay in TPE. These variations in circulatory times can be estimated by measuring the contrast medium arrival time.[17]

Dual-phase CT is routinely performed for hepatic imaging of humans, and accurately estimating TPE is an important part of the procedure. An estimated value for TPE is calculated as a function of contrast medium arrival time and injection duration.[16,17,21,23] This calculation is a simple procedure that could be used in a clinical setting to improve the efficiency and accuracy of dual-phase CT of the liver in veterinary patients. Knowledge of the TPE is important for determining the necessary CT scan delay after contrast medium injection to allow synchronization of image acquisition with peak enhancement. However, this technique has not been validated in veterinary medicine. Furthermore, the accuracy of estimating TPE of the aorta and liver as a function of contrast medium arrival time and injection duration is unknown. The purpose of the study reported here was to measure the accuracy of estimating TPE of the aorta and liver parenchyma for 2 types of injection techniques (fixed injection rate and fixed injection duration), with contrast medium arrival time in the aorta and injection duration used as predictor variables.

Materials and Methods

Animals

Client-owned dogs brought to University Veterinary Teaching Hospital Sydney from May to November 2013 for CT evaluation involving general anesthesia for a problem unrelated to the liver were eligible for inclusion in the study. To qualify for inclusion, dogs were required to have a grossly normal liver as identified via CT, no contraindication to contrast medium administration, and a cephalic vein available for contrast medium injection. The CT assessment criteria for the liver included an unremarkable size, shape, margination, homogeneity on pre- and postcontrast CT scans, and morphology of the hepatic and portal vasculature. Dogs were excluded from the study when they had portosystemic vascular anomalies, congestive heart failure, renal failure, dehydration, or hypertension.

To achieve a uniform distribution of dogs of various body weights, an equal number of dogs of specific body weight categories (0 to 5, 5 to 10, 10 to 15, 15 to 20, 20 to 25, 25 to 30, and > 30 kg) was enrolled to provide a minimum of 2 dogs/category. Owner consent was obtained for all dogs prior to enrollment. The study protocol was approved by the Animal Ethics Committee of the University of Sydney.

Study protocol

Dogs in each body weight category were randomly allocated by drawing of numbers into 1 of

2 groups: group A received contrast medium at a fixed injection rate of 5 mL/s, and group B received contrast medium at a fixed injection duration of 20 seconds. These 2 methods of injection were adopted from techniques used in veterinary radiology. For the procedure, dogs were sedated with butorphanol tartrate[a] (0.2 mg/kg, IM). A 23-gauge IV catheter was placed into a cephalic vein, and anesthesia was induced with alfaxalone[b] (1 to 2 mg/kg, IV). Dogs were endotracheally intubated, and anesthesia was maintained with isoflurane[c] in oxygen, with dogs breathing spontaneously. Hartmann solution[d] was administered at 5 mL/kg/h from the beginning of anesthetic induction through to the point of contrast medium administration. Anesthetic variables that were monitored during the procedure included noninvasively measured arterial blood pressure, heart rate, respiratory rate, end-tidal CO_2 concentration, and Spo_2.

All CT scans were performed with a 16-slice multidetector CT scanner.[e] Dogs were positioned in sternal recumbency. Breath-holds were not used for image acquisition. A precontrast helical scan of the abdomen from the cranial aspect of the diaphragm to the pubis was performed, and images were used to evaluate the liver for focal or diffuse disease. If the liver appeared unremarkable, then a dynamic, single-slice transverse CT scan was performed at the level of the hepatic hilus (cranial to the last tributary to the portal vein [the gastroduodenal vein] and caudal to the first intrahepatic portal branch). A total of 30 single-slice transverse scans were acquired every 2 seconds for a fixed duration of 60 seconds. The settings for the dynamic scan were the same for every dog: beam collimation of 4 data channels with a detector-row width of 0.75 mm (4 X 0.75 mm), a tube potential of 120 kVp, and a tube current of 90 mA.

Injection of contrast medium was started simultaneously with initiation of the dynamic CT scan, although there was an inherent machine delay of 1 second before the start of the first transverse scan. All dogs received the same dose (2 mL/kg) of iohexol[f] (350 mg of iodine/mL), which was administered via the cephalic vein by means of an automated injector.[g] The beginning of contrast medium injection was labeled time 0. After completion of the dynamic CT scan, a postcontrast helical CT scan of the abdomen was performed to evaluate the hepatic and portal vasculature and the liver parenchyma for focal hepatic lesions. Other body regions were subsequently scanned, depending on the initial reason the dog was brought for CT evaluation.

The CT images from the dynamic scan were transferred to a designated workstation and reviewed with image-processing software.[h] Image display was standardized among dog evaluations by use of a window level of 40 and window width of 350. The contrast enhancement values for the aorta and hepatic parenchyma were measured in each dog by drawing a circular ROI in all single-slice images from the dynamic CT scan. In the aorta, the ROI occupied approximately 90% of the vessel diameter. In the hepatic parenchyma, 2 ROIs were placed in the left and right portions of the liver (avoiding intrahepatic vessels), and the mean of the 2 measurements was calculated. To reduce observer variability, all measurements of ROI were made by the same investigator (MAM). Data obtained from the ROIs were exported to spreadsheet software[i] to generate time-attenuation curves for the aorta and liver parenchyma in both injection groups.

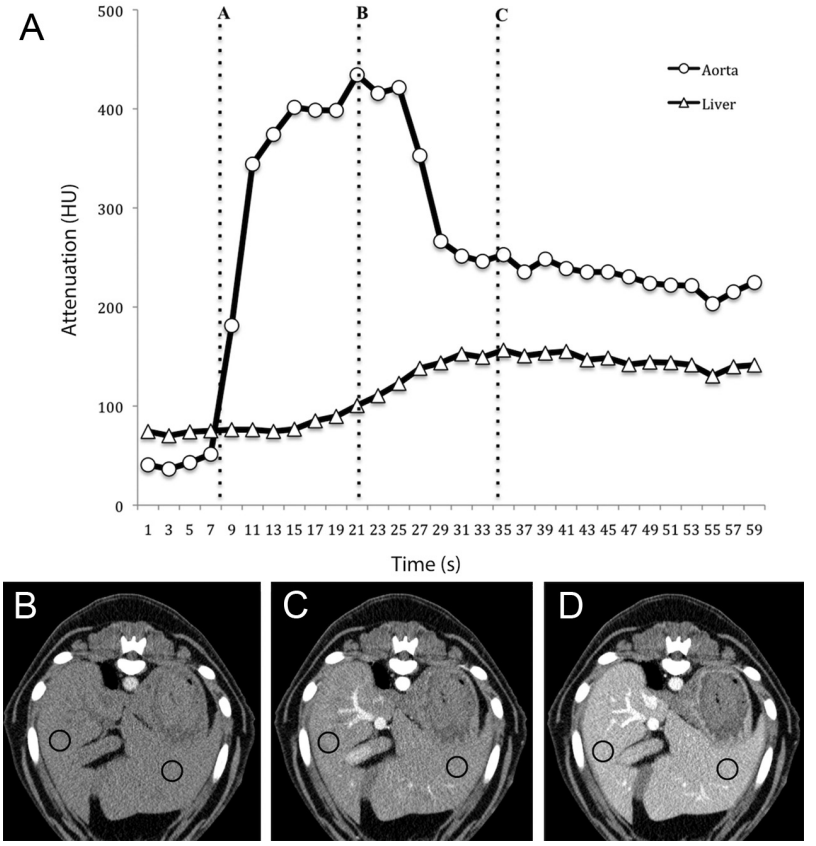

Figure 1—Time-attenuation curve for the aorta and liver during a dynamic CT scan (A) and representative transverse CT images (B–D) at the level of the liver hilus of a dog in which contrast medium (2 mL/kg) was injected IV (beginning at 0 seconds) for a fixed duration (20 seconds). A—The vertical dotted lines represent contrast medium arrival time at the aorta (A), TPE of the aorta (B), and TPE of the liver (C). B—Single-slice image corresponding with contrast medium arrival at the aorta. Notice that no contrast medium is present in other abdominal structures. C—Single-slice image corresponding with peak enhancement of the aorta. Mild diffuse parenchymal enhancement of the liver is evident, caused by perfusion of contrast medium from the hepatic arteries. No vascular enhancement of the hepatic veins is present. D—Single-slice image corresponding with peak enhancement in the liver. In both panels C and D, contrast enhancement of the portal vein is evident.

Information was collected on contrast medium arrival time (from time 0 to the point that aortic enhancement reached 100 HU), TPE of the aorta and liver parenchyma, and peak enhancement values for the aorta and liver parenchyma **(Figure 1)**. Use of 100 HU for estimation of contrast medium arrival time in the aorta was obtained from the human literature.[12] The TPE was defined as the time elapsed from the beginning of the injection to the maximum enhancement value. The peak enhancement value was defined as the maximal value obtained during dynamic CT scanning.

Statistical analysis

Statistical analyses were performed by use of statistical software.[j] Linear mixed models were created to determine the proportion of variation in TPE for aortic and liver parenchymal enhancement that could be explained by contrast medium arrival time, injection duration, and injection technique and to estimate TPE of the aorta and liver parenchyma on the basis of these variables. A block variable representing the 7 body weight groups of dogs was included as a random effect to account for the correlation within each body weight group. Model assumptions were evaluated by creating residual diagnostic plots. If the assumption of linearity appeared invalid, quadratic models were created, but the simpler model was retained if the quadratic model was not statistically superior to the simpler model. All hypothesis tests performed were 2-sided. Values of $P < 0.05$ were considered significant for all analyses.

Results

Animals

Eighteen dogs were included in the study, with 9 dogs in group A (contrast medium administered at a fixed injection rate of 5 mL/s) and 9 dogs in group B (contrast medium administered at a fixed injection duration of 20 seconds). Groups A and B had 2 dogs each in the lowest and highest body weight categories and 1 dog each in the remaining 5 body weight categories. Median body weight in group A was 16 kg (range, 1.5 to 40 kg), and that in group B was 19.8 kg (range, 3.0 kg to 69.4 kg). Group A included 2 Labrador Retrievers and 1 each of Pomeranian, Tibetan Spaniel, Maltese, Cocker Spaniel, Staffordshire Bull Terrier, Australian Shepherd, and Labrador cross. Group B included 2 Labrador Retrievers and 1 each of Miniature Pinscher, Miniature Dachshund, Poodle, Basenji, Shar Pei, Staffordshire Bull Terrier, and Bull Mastiff. Median age in group A was 11 years (range, 6 to 15 years), and that in group B was 11 years (range, 1 to 16 years). Group A included 1 sexually intact female, 2 spayed females, 1 sexually intact male, and 5 neutered males. Group B included 2 sexually intact females, 1 spayed female, 3 sexually intact males, and 3 neutered males. No significant intergroup differences were identified regarding dog age or sex.

Effects of contrast medium injection technique

Values of variables associated with contrast medium administration were summarized by individual dog **(Table 1)**. Contrast medium arrival time ($P < 0.001$), in-

Table 1—Summary of variables for individual dogs with no evidence of liver disease identified via CT in which contrast medium (2 mg/kg) was injected IV at a fixed rate of 5 mL/s (group A) or fixed injection duration of 20 seconds (group B) for dynamic CT scanning.

Dogs	Body weight (kg)	Injection duration (s)	Injection rate (mL/s)	Contrast medium arrival time (s)	TPE of the aorta (s)	Peak aorta enhancement value (HU)	TPE of the liver (s)	Peak liver enhancement value (HU)
Group A								
1	1.5	0.6	5	5	7	778	49	151
2	5	2	5	9	11	754	51	161
3	5.6	2.2	5	7	9	591	31	149
4	14.3	5.6	5	11	15	739	53	136
5	16	6.4	5	9	13	798	37	148
6	21.7	8.4	5	15	21	746	41	140
7	29.9	11.8	5	15	23	900	47	183
8	39	15.6	5	11	23	692	43	157
9	40	16	5	19	31	666	57	183
Median value	16	6.4	5	11	15	746	47	151
Group B								
1	3	20	0.3	11	21	377	51	125
2	5	20	0.5	13	23	511	49	157
3	8.9	20	0.9	7	21	489	55	149
4	11	20	1.1	11	21	607	45	180
5	19.8	20	2	13	25	679	57	173
6	22.5	20	2.2	9	21	434	35	156
7	27.4	20	2.8	13	27	639	57	154
8	49.3	20	4.9	11	23	659	47	192
9	69.4	20	7	13	23	549	51	128
Median value	19.8	20	2	11	23	549	51	156

jection duration ($P < 0.001$), and injection technique ($P = 0.03$) were significantly associated with the observed TPE of the aorta and explained 96.1% of the variation in TPE. The assumptions of linearity, independence of errors, homoscedasticity, and normality of residuals for statistical modeling of the association between aortic TPE and these 3 variables were approximately met. There were no significant outliers or influential observations. The final model was as follows:

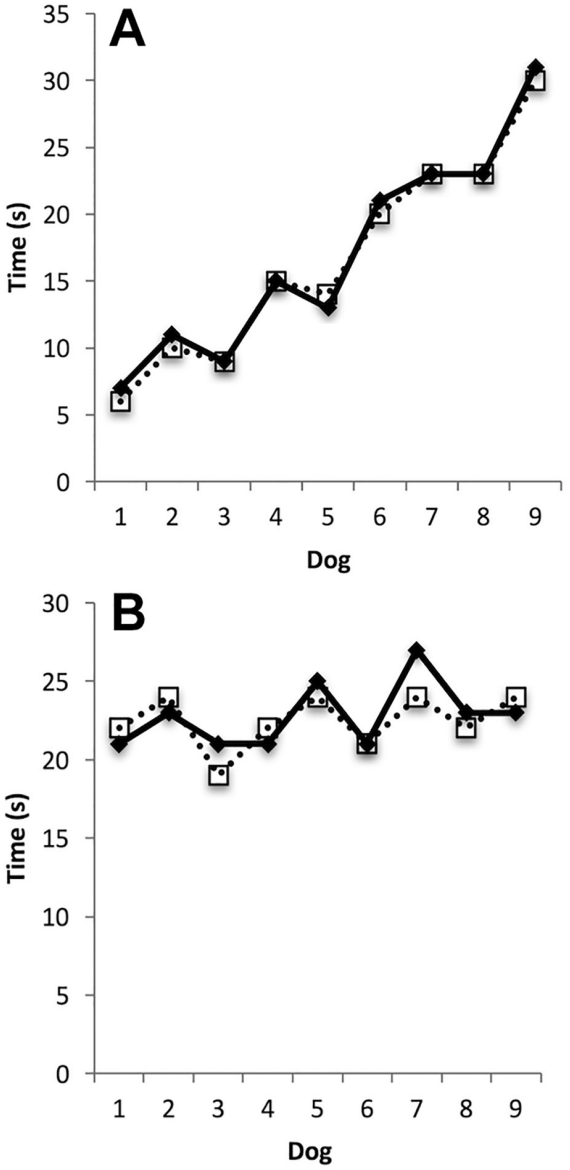

Figure 2—Observed (diamonds) and estimated (squares) TPE of the aorta for individual dogs (ordered by increasing body weight) with no evidence of liver disease identified via CT in which contrast medium (2 mL/kg) was injected IV at a fixed rate of 5 mL/s (A) or fixed injection duration of 20 seconds (B) for dynamic CT scanning. The regression equation for TPE estimates for the fixed injection rate was as follows: 0.8 X (contrast medium arrival time + injection duration)+1.6. The regression equation for TPE estimates for the fixed injection duration was as follows: 0.8 X (contrast medium arrival time + injection duration) – 2.6.

Estimated aortic TPE = (0.8 X contrast medium arrival time) + (0.8 X injection duration) – 2.6 + (4.2 X injection technique)

where a value of 1 was assigned when the injection technique was fixed rate and a value of 0 was assigned when the injection technique was fixed duration. Therefore, when the injection technique was via a fixed injection rate, the model for estimated aortic TPE was (0.8 X contrast medium arrival time) + (0.8 X injection duration) – 2.6 + (4.2 X 1). Further simplified, the model was 0.8 X (injection duration + contrast medium arrival time) + 1.6.

When the injection technique was via a fixed duration, the model for estimated aortic TPE was (0.8 X contrast medium arrival time) + (0.8 X injection duration) – 2.6 + (4.2 X 0). This simplified to 0.8 X (injection duration + contrast medium arrival time) – 2.6. Values for estimated aortic TPE for both injection techniques were plotted against observed TPEs collected from the dynamic CT scan **(Figure 2)**.

The equations for estimated aortic TPE were further simplified by consideration of dog body weight and the known dose of contrast medium **(Table 2)**. When a fixed injection duration technique was used for dogs with various body weights, the constant in the equation became fixed and the only unknown variable was contrast medium arrival time. When a fixed injection rate technique was used for dogs with various body weights, the constant in the equation varied with body weight and the contrast medium arrival time remained an unknown variable.

The estimated TPE of the liver as predicted by contrast medium arrival time ($P = 0.21$), injection duration ($P = 0.64$), and injection technique ($P = 0.40$) was not significantly different from the mean of the observed hepatic TPEs. The regression model that included those 3 variables explained only 6.4% of the variation in hepatic TPE.

Discussion

The purpose of the present study was to measure the accuracy of estimating TPE of the aorta and liver parenchyma in dogs by use of dynamic CT, taking into consideration contrast medium arrival time, injection duration, and injection technique as predictor variables. These 3 variables accounted for 96.1% of the variation in aortic TPE but could not explain variations in hepatic TPE. Therefore, contrast medium arrival time and injection duration are important factors to consider when determining aortic TPE during CT. This is in agreement with previous reports[17,24] and can be explained by the physiologic distribution of contrast medium within the body.

Peak enhancement of the aorta is expected to occur after the full dose of contrast medium has been delivered, with additional time allowed for the medium to move from the venous access site to the aorta. For any given injection rate, a constant inflow of contrast medium occurs throughout the injection duration, which contributes to progressive opacification of the aorta. A brief additional period is required

Table 2—Simplified regression equations for estimating TPE of the aorta by contrast medium injection technique and body weight for the dogs in Table 1.

Body weight (kg)	Volume of contrast medium (2 mL/kg)	Injection rate (mL/s)	Injection duration (s)	Expanded equation	Simplified equation
Fixed injection rate					
5	10	5	2	$(0.8 \times T_{arr}) + (0.8 \times 2) + 1.6$	$(0.8 \times T_{arr}) + 3.2$
10	20	5	4	$(0.8 \times T_{arr}) + (0.8 \times 4) + 1.6$	$(0.8 \times T_{arr}) + 4.8$
15	30	5	6	$(0.8 \times T_{arr}) + (0.8 \times 6) + 1.6$	$(0.8 \times T_{arr}) + 6.4$
20	40	5	8	$(0.8 \times T_{arr}) + (0.8 \times 8) + 1.6$	$(0.8 \times T_{arr}) + 8$
25	50	5	10	$(0.8 \times T_{arr}) + (0.8 \times 10) + 1.6$	$(0.8 \times T_{arr}) + 9.6$
30	60	5	12	$(0.8 \times T_{arr}) + (0.8 \times 12) + 1.6$	$(0.8 \times T_{arr}) + 11.2$
35	70	5	14	$(0.8 \times T_{arr}) + (0.8 \times 14) + 1.6$	$(0.8 \times T_{arr}) + 12.8$
40	80	5	16	$(0.8 \times T_{arr}) + (0.8 \times 16) + 1.6$	$(0.8 \times T_{arr}) + 14.4$
Fixed injection duration (s)					
5	10	0.5	20	$(0.8 \times T_{arr}) + (0.8 \times 20) - 2.6$	$(0.8 \times T_{arr}) + 13.4$
10	20	1.0	20	$(0.8 \times T_{arr}) + (0.8 \times 20) - 2.6$	$(0.8 \times T_{arr}) + 13.4$
15	30	1.5	20	$(0.8 \times T_{arr}) + (0.8 \times 20) - 2.6$	$(0.8 \times T_{arr}) + 13.4$
20	40	2.0	20	$(0.8 \times T_{arr}) + (0.8 \times 20) - 2.6$	$(0.8 \times T_{arr}) + 13.4$
25	50	2.5	20	$(0.8 \times T_{arr}) + (0.8 \times 20) - 2.6$	$(0.8 \times T_{arr}) + 13.4$
30	60	3.0	20	$(0.8 \times T_{arr}) + (0.8 \times 20) - 2.6$	$(0.8 \times T_{arr}) + 13.4$
35	70	3.5	20	$(0.8 \times T_{arr}) + (0.8 \times 20) - 2.6$	$(0.8 \times T_{arr}) + 13.4$
40	80	4.0	20	$(0.8 \times T_{arr}) + (0.8 \times 20) - 2.6$	$(0.8 \times T_{arr}) + 13.4$

The equation for the fixed rate technique simplified to 0.8 × (injection duration + contrast medium arrival time) + 1.6, and that for the fixed duration technique simplified to 0.8 × (injection duration + contrast medium arrival time) – 2.6.

T_{arr} = Contrast medium arrival time.

for contrast medium to move from the venous access site to the heart, through the pulmonary vasculature, and then to the aorta. This brief period relates to the contrast medium arrival time in the aorta and is dependent on cardiac output.[17,23]

The regression formula for estimating TPE obtained in the present study (0.8 × [injection duration + contrast medium arrival time] ± a constant) can be used in a clinical setting when planning dual-phase CT evaluation of the liver in dogs. The regression formula will give an accurate estimation of aortic TPE, which can be used to determine the appropriate timing for the arterial phase and ensure optimal synchronization with peak enhancement.

To solve the regression formula for estimating TPE, the injection duration and contrast medium arrival time need to be identified. If a fixed injection rate is used, then the injection duration is obtained by dividing the contrast medium volume by the injection rate. If a fixed injection duration is used, then this value can be directly incorporated into the regression formula. Fixed injection duration has been previously used for dual-phase CT in dogs.[7,8] Second, the contrast medium arrival time can be identified by administering a test bolus. Once the injection duration and contrast medium arrival time are known, then the estimated TPE can be calculated by use of the regression formula. This estimated TPE should not be directly used as the scan delay (the interval from the beginning of contrast medium injection to the time of initial image acquisition) because that would result in the scan starting at the peak of enhancement and would mainly capture a period of progressive decline in contrast. Instead, the estimated TPE should coincide with the middle of the CT acquisition window. To achieve this, the scan delay is calculated as the estimated TPE minus half of the acquisition period.[17] During the arterial phase, scans should be performed in a cranial-to-caudal direction, corresponding with the direction of contrast medium flow in the aorta.

In addition to the use of a test bolus, an alternative method for identifying contrast medium arrival time is the use of bolus tracking. The advantage of this method over the test bolus procedure is that only a single injection of contrast medium is required and the duration of the CT scan procedure can be reduced.[25] Bolus tracking is automatically linked to the start of the diagnostic CT scan, and therefore contrast medium arrival time cannot be predetermined when this technique is used. This represents a problem because contrast medium arrival time is needed to solve the regression formula for estimating aortic TPE. As a solution, we suggest use of a regression coefficient of 1 instead of 0.8 for contrast medium arrival time. As a result, the whole value for contrast medium arrival time as identified from the bolus-tracking procedure would be used in the regression formula, and the remaining TPE would be given by (0.8 × injection duration) ± a constant. This modification may lead to a minimal overestimation of TPE.

None of the 3 variables significantly associated with aortic TPE were associated with TPE of the liver parenchyma of dogs in the present study. The regression formula was no better than the mean of observed values for estimation of TPE of the dogs used. Therefore, we propose using the mean of observed TPE val-

ues (45 seconds for group A and 50 seconds for group B, from the beginning of contrast medium injection) as an estimate of TPE for other dogs. Similar to the arterial phase, the CT scan delay for the hepatic phase is calculated as the estimated TPE of the liver minus half of the acquisition period. Use of the mean observed value as an estimate of hepatic TPE is considered a feasible option on the basis of previous research in which little to no change was demonstrated in the timing of peak enhancement in the liver in various conditions.[15] The results reported here were in agreement with those of previous research, given that the timing of peak liver enhancement was fairly constant regardless of the injection duration or dog body weight. In addition, the period of peak liver enhancement is much broader than that of arterial enhancement, which provides a wider temporal window for synchronization with the hepatic phase scan.[17] For the hepatic phase, scanning should be performed in a caudal-to-cranial direction, corresponding with portal blood flow.

The capability of the CT machine in terms of speed of image acquisition has an impact on the CT scan protocol used for dual-phase CT of the liver.[17] Speed of image acquisition is largely dependent on the number of detector rows, pitch, and rotation time. Matching the duration of image acquisition with injection duration is recommended to ensure sufficient contrast enhancement throughout both scan phases. If injection duration is much briefer than the acquisition window, the TPE is expected to occur early, and the CT scan may either miss peak enhancement or mainly capture a period of progressive decline in contrast enhancement. If injection duration is much longer than the acquisition window, then the scan may have finished before the full volume of contrast medium has been administered, which means some of the dose would not contribute to diagnostic usefulness.

In the present study, a multirow CT scanner with 16 detector rows was used, and the acquisition time for the canine abdomen was up to 20 seconds (for a large-breed dog). Therefore, a fixed injection duration of 20 seconds was selected to match the acquisition window. This injection technique is also one of the published techniques for dual-phase CT of the liver.[7] When a CT scanner with 64 detector rows is used, the acquisition times will be relatively brief, and the injection duration should be reduced to match this. Both an arterial and parenchymal phase would be achievable with this type of rapid CT technology. Conversely, a single–detector row CT scanner would have relatively prolonged acquisition times. The injection duration can be increased to match this and still achieve a parenchymal phase CT scan of the liver. However, an arterial phase would be unlikely to be achieved because the long injection duration is associated with a slow injection rate and this would result in insufficient contrast enhancement of the arteries. Although shortening the injection duration by injecting contrast medium faster will increase the magnitude of contrast enhancement, this practice would not be appropriate when single-slice CT machinery is used because peak enhancement would likely occur much earlier than image acquisition.

The present study had some limitations. Dogs with nonhepatic illnesses were used rather than healthy dogs. This was justified by the fact that multiphase CT evaluations are often indicated for diseased patients. We therefore chose a study population that we believed represented the target clinical population. Although the presence of hepatic disease was excluded through performance of pre- and postcontrast CT scans of the liver, cytologic and histopathologic evaluation of liver samples was not always performed, nor was serum biochemical analysis. Therefore, we could not rule out the possibility that some dogs may have had microcirculatory liver disease, which could have affected the TPE. Finally, multiphasic CT evaluations of the liver are also indicated for patients with macroscopic liver disease, and it is unknown whether the presence of macroscopic disease would alter the flow of contrast medium and affect timing of contrast enhancement. Additional studies may be needed to evaluate the effect of gross liver disease on the timing of contrast enhancement.

The study reported here revealed that contrast medium arrival time, injection duration, and injection technique can be used to estimate aortic TPE. The combination of these variables in a regression formula provides an accurate and relatively quick way of estimating TPE, which can then be used to calculate the necessary scan delay for dual-phase CT scans. Unlike aortic TPE, hepatic TPE could not be significantly explained by these 3 variables.

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Footnotes

a. Butorgesic, Troy Laboratories Pty Ltd, Smithfield, NSW, Australia.
b. Alfaxan, Jurox Pty Ltd, Rutherford, NSW, Australia.
c. Isoflo, Abbott Australasia Pty Ltd, Botany, NSW, Australia.
d. Viaflex, Baxter Healthcare Pty Ltd, Toongabbie, NSW, Australia.
e. Philips 16-slice Brilliance CT V2.3, Phillips Medical Systems Netherlands, Eindohoven, Netherlands.
f. Omnipaque, GE Healthcare Australia Pty Ltd, Rydalmere, NSW, Australia.
g. Empower CTA, E-Z-EM Inc, Westbury, NY.
h. Osirix, version 4.1.2, OsiriX Foundation, Geneva, Switzerland.
i. Numbers, version 3.5.2, Apple Pty Ltd, Apple, Cupertino, Calif.
j. SAS, version 9.4, SAS Institute Inc, Cary, NC.

References

1. Zwingenberger AL, Schwarz T. Dual-phase CT angiography of the normal canine portal and hepatic vasculature. *Vet Radiol Ultrasound* 2004;45:117–124.

2. Frank P, Mahaffey M, Egger C, et al. Helical computed tomographic portography in ten normal dogs and ten dogs with a portosystemic shunt. *Vet Radiol Ultrasound* 2003;44:392–400.
3. Bertolini G, Rolla EC, Zotti A, et al. Three-dimensional multislice helical computed tomography techniques for canine extra-hepatic portosystemic shunt assessment. *Vet Radiol Ultrasound* 2006;47:439–443.
4. Zwingenberger AL, McLear RC, Weisse C. Diagnosis of arterioportal fistulae in four dogs using computed tomographic angiography. *Vet Radiol Ultrasound* 2005;46:472–477.
5. Schwarz T, Rossi F, Wray JD, et al. Computed tomographic and magnetic resonance imaging features of canine segmental caudal vena cava aplasia. *J Small Anim Pract* 2009;50:341–349.
6. Fischetti AJ, Kovak J. Imaging diagnosis: azygous continuation of the caudal vena cava with and without portocaval shunting. *Vet Radiol Ultrasound* 2008;49:573–576.
7. Kutara K, Seki M, Ishikawa C, et al. Triple-phase helical computed tomography in dogs with hepatic masses. *Vet Radiol Ultrasound* 2014;55:7–15.
8. Fukushima K, Kanemoto H, Ohno K, et al. CT characteristics of primary hepatic mass lesions in dogs. *Vet Radiol Ultrasound* 2012;53:252–257.
9. Mai W, Caceres AV. Dual-phase computed tomographic angiography in three dogs with pancreatic insulinoma. *Vet Radiol Ultrasound* 2008;49:141–148.
10. Oliver JH, Baron RL, Federle MP, et al. Detecting hepatocellular carcinoma: value of unenhanced or arterial phase CT imaging or both used in conjunction with conventional portal venous phase contrast-enhanced CT imaging. *AJR Am J Radiol* 1996;167:71–77.
11. Ohashi I, Hanafusa K, Yoshida T. Small hepatocellular carcinomas: two-phase dynamic incremental CT in detection and evaluation. *Radiology* 1993;189:851–855.
12. Baron RL. Understanding and optimizing use of contrast material for CT of the liver. *AJR Am J Radiol* 1994;163:323–331.
13. Honda H, Matsuura Y, Onitsuka H, et al. Differential diagnosis of hepatic tumors (hepatoma, hemangioma, and metastasis) with CT: value of two-phase incremental imaging. *AJR Am J Radiol* 1992;159:735–740.
14. Hollett MD, Jeffrey RB, Nino-Murcia M, et al. Dual-phase helical CT of the liver: value of arterial phase scans in the detection of small (≤ 1.5cm) malignant hepatic neoplasms. *AJR Am J Radiol* 1995;164:879–884.
15. Erturk SM, Ichikawa T, Sou H, et al. Effect of duration of contrast material injection on peak enhancement times and values of the aorta, main portal vein, and liver at dynamic MDCT with the dose of contrast medium tailored to patient weight. *Clin Radiol* 2008;63:263–271.
16. Awai K, Hori S. Effect of contrast injection protocol with dose tailored to patient weight and fixed injection duration on aortic and hepatic enhancement at multidetector-row helical CT. *Eur Radiol* 2003;13:2155–2160.
17. Bae KT. Intravenous contrast medium administration and scan timing at CT: considerations and approaches. *Radiology* 2010;256:32–61.
18. Bouma JL, Aronson LR, Keith DG, et al. Use of computed tomography renal angiography for screening feline renal transplant donors. *Vet Radiol Ultrasound* 2003;44:636–641.
19. Brown JC Jr, Chanoit G, Reeder J. Complex extrahepatic portocaval shunt with unusual caval features in a cat: computed tomographic characterisation. *J Small Anim Pract* 2010;51:227–230.
20. Bae KT, Heiken JP, Brink JA. Aortic and hepatic contrast medium enhancement at CT. Part I. Prediction with a computer model. *Radiology* 1998;207:647–655.
21. Awai K, Hiraishi K, Hori S. Effect of contrast material injection duration and rate on aortic peak time and peak enhancement at dynamic CT involving injection protocol with dose tailored to patient weight. *Radiology* 2004;230:142–150.
22. Makara M, Dennler M, Kuhn K, et al. Effect of contrast medium injection duration on peak enhancement and time to peak enhancement of canine pulmonary arteries. *Vet Radiol Ultrasound* 2011;52:605–610.
23. Bae KT, Heiken JP, Brink JA. Aortic and hepatic peak enhancement at CT: effect of contrast medium injection rate—pharmacokinetic analysis and experimental porcine model. *Radiology* 1998;206:455–464.
24. Bae KT, Tran HQ, Heiken JP. Multiphasic injection method for uniform prolonged vascular enhancement at CT angiography: pharmacokinetic analysis and experimental porcine model. *Radiology* 2000;216:872–880.
25. Mai W, Suran JN, Caceres AV, et al. Comparison between bolus tracking and timing-bolus techniques for renal computed tomographic angiography in normal cats. *Vet Radiol Ultrasound* 2013;54:343–350.