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Computed tomographic evaluation of portal vein indices in cats with the extrahepatic portosystemic shunts

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ABSTRACT

Importance: The portal vein to aorta (PV/Ao) ratio is used to assess the clinical significance of extrahepatic portosystemic shunt (EHPSS). Previous studies using computed tomography (CT) were conducted in dogs but not in cats.
Objective: This study aimed to establish normal reference values for PV indices (PV/Ao ratio and PV diameter) in cats and determine the usefulness of these for predicting symptomatic EHPSS.
Methods: This study included 95 dogs and 114 cats that underwent abdominal CT. The canine normal (CN) group included dogs without EHPSS. The cats were classified into feline normal (FN, 88/114), feline asymptomatic (FA, 16/114), and feline symptomatic (FS, 10/114) groups. The PV and Ao diameters were measured in axial cross-sections.
Results: The group FN had a higher PV/Ao ratio than the group CN ($p < 0.001$). Within the feline groups, the PV indices were in the order FN > FA > FS (both $p < 0.001$). The mean PV diameter and PV/Ao ratio for group FN were 5.23 ± 0.77 mm and 1.46 ± 0.19, respectively. The cutoff values between groups FN and FS were 4.115 mm for PV diameter (sensitivity, 100%; specificity, 97.7%) and 1.170 for PV/Ao ratio (90%, 92.1%). The cutoff values between group FA and FS were 3.835 mm (90%, 93.8%) and 1.010 (70%, 100%), respectively.
Conclusions and Relevance: The results demonstrated significant differences in PV indices between dogs and cats. In cats, the PV/Ao ratio demonstrated high diagnostic performance for symptomatic EHPSS. The PV diameter also performed well, in contrast to dogs.

Keywords: CT; feline; PSS; PV/Ao ratio; PV diameter

INTRODUCTION

Portosystemic shunts (PSS) are vascular anomalies that enable blood from the stomach, intestines, pancreas, and spleen to bypass the liver and directly enter systemic venous circulation [1,2]. They can be classified as congenital or acquired, single or multiple, and intrahepatic or extrahepatic based on the time of shunt vessel occurrence, their number, and the relationship between their location and the liver parenchyma, respectively [3].

The prevalence of PSS in cats is lower than that in dogs, with a high frequency of single congenital extrahepatic PSS (EHPSS). Cases of intrahepatic PSS in cats have been

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Conflict of Interest
The authors declare no conflicts of interest.

documented but are much less common [4-7]. Similar to dogs, most cats that present with PSS are < 1 year of age, although cases are intermittently reported at older ages [4,6]. While cases in purebred cats, such as the Persian, Siamese, Himalayan, and Burmese breeds, have been reported, domestic shorthair comprises the largest breed group [6,7].

PSS impairs the ability of the liver to metabolize or clear substances and causes the accumulation of toxins in the systemic circulation, which alters the functioning of the central nervous system. Consequently, clinical signs associated with nervous system abnormalities are frequently observed. Hypersalivation, seizures, ataxia, tremors, altered mental status, and depression are the most common symptoms observed in cats [7-9]. Regarding the underlying mechanism, an increased fasting ammonia concentration is considered a closely related and sensitive factor [10].

Computed tomography (CT) is the gold standard for diagnosing PSS. CT can noninvasively and rapidly acquire images, reformat them to multiple planes, effectively determine shunt vessel termination, and assist in anatomical orientation and identification [11,12].

The ratio between the luminal diameters of the portal vein and the aorta (PV/Ao) is an index frequently used to assess the clinical significance of shunt vessels. This index was initially introduced in a study using ultrasonography (US) to assess congenital PSS in dogs and cats. The study suggested that the decrease in PV diameter in these cases could be effectively evaluated using the PV/Ao ratio at the porta hepatis level [13].

Subsequent studies using CT in dogs have led to further advancements in this field. These studies included an analysis of the PV/Ao ratio based on the EHPSS type, a comparison according to symptoms, and investigation of the normal ratio in healthy dogs, respectively [14-16]. However, to the best of our knowledge, no studies have reported PV-related indices (PV diameter and PV/Ao ratio) using CT in cats.

The present study assumed that PV-related indices differ between dogs and cats and that differences among cats may depend on the EHPSS and symptoms. Thus, this study used CT images to 1) compare the differences in PV-related indices between dogs and cats; 2) establish normal indices for cats; 3) compare the differences among three feline groups: cats without EHPSS, with asymptomatic EHPSS, and with symptomatic EHPSS; and 4) determine the usefulness of these indices for predicting symptomatic EHPSS in cats.

METHODS

Case selection

This retrospective multicenter study included dogs and cats that underwent abdominal CT examinations at the Kangwon National University Veterinary Teaching Hospital (Chuncheon, Korea) and Wonju Sky Animal Medical Center (AMC) (Wonju, Korea) between January 2019 and April 2023. Cases without EHPSS were collected through this process.

Case selection was additionally performed by recruiting cases of cats diagnosed with EHPSS through abdominal CT examinations at eight veterinary hospitals in the Republic of Korea: Wonju Sky AMC, Soo AMC (Seoul, Korea), The Care AMC (Guri, Korea), Bon AMC (Suwon, Korea), Bien AMC (Bucheon, Korea), Daegu Jukjeon AMC (Daegu, Korea), Times AMC (Suwon, Korea), and Nowon VIP AMC (Seoul, Korea).

Cases with intrahepatic shunts or multiple collateral vessels were excluded, whereas those with a single splenogonadal shunt were included. Cases with thrombosis at the measurement site and with suspected chronic hepatitis or cirrhosis during the imaging assessment were also excluded, as were cases in which the PV was displaced or compressed due to changes in the abdominal structures, including the liver.

Data collection

Information on breed, age, sex, body weight, history, clinical signs, physical examination and indications for CT examination was obtained from medical records. Cases with documented hyperammonemia were included. All CT images were exported in Digital Imaging and Communications in Medicine (DICOM) format through the Picture Archiving and Communication Systems program of each hospital and included in this study.

Grouping of selected cases

The canine normal (CN) group included dogs without EHPSS for comparison with the feline normal (FN) group. Feline cases were classified into three groups based on the presence or absence of EHPSS and associated symptoms, such as hyperammonemia, neurological signs, or ammonium urate uroliths. The FN group included cases without EHPSS. Felines with EHPSS without and with symptoms were classified into the FA and FS groups, respectively.

CT analysis

CT images were acquired based on axial cross-sections obtained from animals placed in sternal recumbent position under general anaesthesia and administered intravenous contrast medium. In the image review process, only images in which the margins of the PV and Ao were clearly identified were selected.

All measurements were conducted by an experienced veterinarian using an electronic caliper on a DICOM workstation (ViewRex; TechHeim, Korea), specifically on post-contrast soft-tissue window CT images. The PV diameter was measured on axial images halfway between the right portal branch, the liver and gastroduodenal vein [14,15]. The point where the direction and diameter of the vessel were maintained as constant as possible was selected. The Ao diameter was measured on the same axial section as that of the PV [14,15]. The angles of the measurement lines were perpendicular to the vessel direction. PV/Ao ratios were calculated using these two values.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics, version 26.0 (IBM, USA). Statistical tests were conducted on the CT measurements (PV diameter and PV/Ao ratio). For all groups, the Shapiro–Wilk test was used to assess the normality of the data distributions. The results were considered significant for $p < 0.05$.

Comparison of dogs and cats without EHPSS

The CN and FN groups were compared using the Mann–Whitney *U* test to confirm the presence of significant differences in the median values of measurements between the two species.

Indices of CT images of cats without EHPSS

The indices of the CT images in the FN group were derived using descriptive statistics. Pearson correlation analysis was performed to investigate the correlation with body weight and age.

Intergroup comparison of the three feline groups

The Kruskal–Wallis test with post-hoc Bonferroni correction was performed to determine the differences in the median values of the measurements between the three feline groups (FN, FA, and FS). To compare and assess the diagnostic performance of measurements (PV diameter and PV/Ao ratio) from CT images, receiver operating characteristic (ROC) curve analyses were conducted twice: first for the FN and FS groups and then for the FA and FS groups. Youden's index was used to determine the sensitivity, specificity, positive predictive value, negative predictive value, and cut-off value for each measurement.

RESULTS

Case characteristics

This study included 95 dogs and 114 cats. The CN group comprised 95 dogs without EHPSS, predominantly consisting of Maltese, mixed-breeds, and Poodles, including a diverse range of breeds. The FN group comprised 88 cats without EHPSS, with domestic shorthair representing the predominant breed. Among 26 cat cases with EHPSS, the FA and FS groups included 16 asymptomatic and 10 symptomatic cats, respectively.

The CN and FN groups had the highest proportions of castrated males (CM) and spayed females (SF), with similar frequencies. The FA group contained three CMs and 13 SFs. The FS group consisted of one intact male, five CMs, and four SFs. The mean ± SD, minimum, and maximum values for age and body weight in each group are listed in **Table 1**. The FS group had a significantly lower body weight and age than the other two feline groups (all $p < 0.01$). Any other significant differences were not observed between the FN and FA groups.

Cases from the FS group presented with a combination of one or more of the following symptoms: hyperammonemia (n = 10), seizures (n = 2), hypersalivation (n = 7), nystagmus (n = 1), syncope (n = 2), altered mental status (n = 4), and ammonium urate uroliths (n = 2).

Regarding the types of shunts identified, the splenogonadal type (n = 11) was the most frequent in the FA group, followed by the splenophrenic type (n = 3). Furthermore, a porto-internal thoracic shunt (n = 1) and a splenorenal shunt (n = 1) were also observed. One case of

Table 1. Descriptive statistics and means comparison of age and body weight in each group

Groups	CN	FN	FA	FS
No.	95	88	16	10
Age (mon)				
Mean ± SD	121.01 ± 36.49	83.09 ± 49.52	102.75 ± 29.06	31.70[a] ± 36.71
Min	12	5	24	8
Max	192	204	144	132
Body weight (kg)				
Mean ± SD	9.31 ± 9.9	4.84 ± 1.72	5.08 ± 1.79	3.16[a] ± 0.73
Min	1.8	2.20	2	1.92
Max	43	9.44	8.5	4
Sex				
IM	5	6		1
CM	34	39	3	5
IF	23	5		
SF	33	38	13	4

CN, canine normal; FN, feline normal; FA, feline asymptomatic; FS, feline symptomatic; Max, maximum; Min, minimum; IM, intact male; CM, castrated male; IF, intact female; SF, spayed female.
[a]Group FS showed significantly lower age and body weight values than the other feline groups ($p < 0.01$).

Table 2. Comparisons of PV diameter and PV/Ao ratio between each group

Groups	CN	FN	FA	FS	Bonferroni (group feline)
PV diameter	6.20[a] (5.49–7.81)	5.19[a] (4.52–5.75)	4.31 (3.99–4.90)	2.84 (1.64–3.80)	FN[b,c] > FA[b,d] > FS[c,d]
PV/Ao ratio	1.28[a] (1.14–1.35)	1.45[a] (1.33–1.61)	1.19 (1.16–1.24)	0.89 (0.54–1.09)	FN[b,c] > FA[b,d] > FS[c,d]

Values are presented as median (interquartile range).
PV, portal vein; Ao, aorta; CN, canine normal; FN, feline normal; FA, feline asymptomatic; FS, feline symptomatic.
[a,b,c,d]Significant differences in values between the same superscripts ($p < 0.01$).

splenogonadal-type coexisted with the left gastrophrenic-type. Conversely, in the FS group, the splenophrenic type (n = 6) was identified most frequently, followed by the splenogonadal (n = 3) and left gastrophrenic types (n = 1).

CT measurements

The PV diameter (mm) of the CN group (median, 6.20; interquartile range [IQR], 5.49–7.81) was significantly larger than that of the FN group (median, 5.19; IQR, 4.52–5.75) ($p < 0.001$). In contrast, the FN group (median, 1.45; IQR, 1.33–1.61) demonstrated a larger PV/Ao ratio than that of the CN group (median, 1.28; IQR, 1.14–1.35) ($p < 0.001$) (**Table 2**).

Based on the analysis of the descriptive statistics in the FN group that satisfied normality, the mean ± SD of PV diameter in cats without EHPSS was 5.23 ± 0.77 mm, and the PV/Ao ratio was 1.46 ± 0.19. The PV and Ao diameters in this group were positively correlated with body weight to a moderate degree ($r = 0.415$, $p < 0.001$ and $r = 0.532$, $p < 0.001$, respectively). The Ao diameter positively correlated with age, but only weakly ($r = 0.342$, $p < 0.01$).

The three feline groups demonstrated significant differences in PV diameter and PV/Ao ratio (both $p < 0.001$). In the post-hoc analysis, when comparing two groups at a time, the PV diameter (mm) was the smallest in the FS group (median, 2.84; IQR, 1.64–3.80), followed by the FA (median, 4.31; IQR, 3.99–4.90) and FN (median, 5.19; IQR, 4.52–5.75) groups. Similarly, the PV/Ao ratio was also smallest in the FS group (median, 0.89; IQR, 0.54–1.09), followed by the FA (median, 1.19; IQR, 1.16–1.24) and FN (median, 1.45; IQR, 1.33–1.61) groups (**Table 2**).

CT prediction of symptomatic EHPSS

ROC analysis was performed to evaluate whether the FN and FS groups could be differentiated according to the PV diameter and PV/Ao ratio (**Fig. 1**). The areas under the curve (AUCs) displayed similarly high results, at 0.997 for the PV diameter and 0.956 for the PV/Ao ratio (all $p < 0.001$). The sensitivity and specificity of the PV diameter (100%, 97.72%) were relatively higher than those of the PV/Ao ratio (90%, 92.05%). The cutoff values for the PV diameter and PV/Ao ratio were 4.115 mm and 1.170, respectively.

ROC analysis was also used to evaluate the ability to distinguish between the FA and FS groups based on the PV diameter and PV/Ao ratio (**Fig. 2**). The AUC for the PV diameter was 0.944, which was slightly higher than that for the PV/Ao ratio (0.862) ($p < 0.001$ and $p < 0.01$, respectively). The sensitivity of the PV diameter was 90%, which was relatively higher than that of the PV/Ao ratio (70%), whereas the specificity of the PV/Ao ratio was 100%, relatively higher than that of the PV diameter (93.75%). The cutoff values were 3.835 mm and 1.010 for the PV diameter and PV/Ao ratio, respectively.

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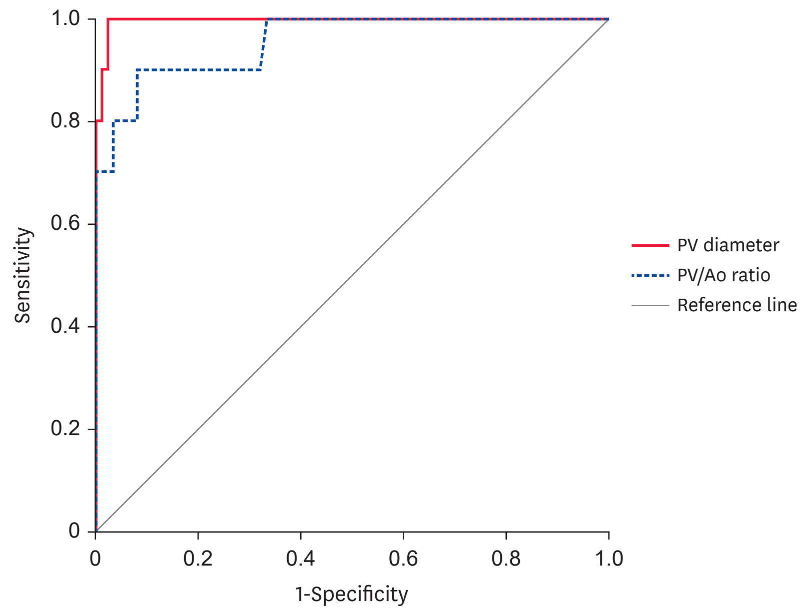

Fig. 1. Receiver operating characteristic curves to differentiate cats in the FN and FS groups.
PV, portal vein; Ao, aorta.

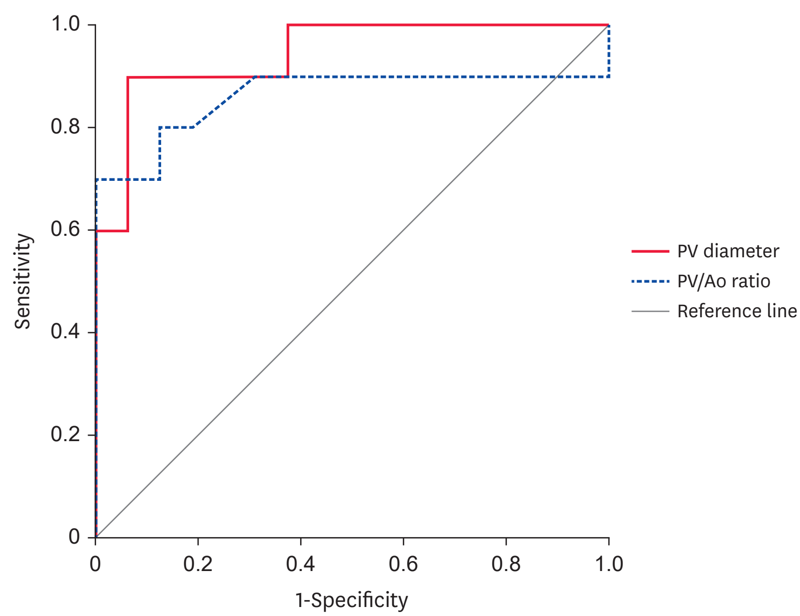

Fig. 2. Receiver operating characteristic curves to differentiate cats in the FA and FS groups.
PV, portal vein; Ao, aorta.

DISCUSSION

For all EHPSS cases, including the FA and FS groups, the domestic shorthair had the highest frequency of all cat breeds, accounting for 11 of 16 cases and five of 10 cases, respectively. Other studies have reported similar results, with the species forming a large group of breeds [6,7]. This finding may be due to the skewed distribution of domestic shorthair worldwide, rather than a potential predisposition to EHPSS.

The FS group exhibited lower age and body weight than the other two feline groups. Symptomatic EHPSS is more likely to be diagnosed in young individuals because the disease tends to manifest at an early age [17]. Therefore, an immature state due to age can influence body weight, and EHPSS may be accompanied by growth failure or weight loss [8]. These characteristics were reflected in the results of the present study.

Previous studies that have analyzed the classification and distribution of the anatomy of EHPSS in cats are rare, particularly when considering the symptoms. In cats, the left gastric caval type has been suggested as the most common type of EHPSS [3,18,19]. Studies on PSS surgery have also reported a high frequency of this type, presumably in symptomatic cases requiring surgery [6,20]. In addition, splenocaval, splenogonadal, splenorenal, and portoazygos shunt types have been reported in cats [7,21,22]. In dogs, portocaval shunts are most common in symptomatic EHPSS, whereas non-portocaval shunts, including the portophrenic or portoazygos type, account for a high proportion of asymptomatic EHPSS cases [14,17]. The FA and FS groups differed in the predominant shunt type, with the former being splenogonadal and the latter being splenophrenic. Both types are non-portocaval shunts.

The splenogonadal shunts occurred in both FA and FS groups. This type of shunt connects the splenic vein to the left renal vein via the left gonadal vein, which ultimately drains into the caudal vena cava [23]. Two hypotheses have been proposed for dogs and cats, acquired or congenital, although the clinical significance remains unknown [22,24]. One study suggested that the development of a splenogonadal shunt in spayed female cats could be caused by the formation of adhesions after a previous ovariohysterectomy [21]. All the splenogonadal types in this study were consistently detected in SF. Typically, single EHPSS cases that directly connect the PV and systemic venous circulation are considered congenital [7,8,25]. However, cases of suspected acquired EHPSS due to portal hypertension and incidental findings have been reported [22]. Despite this controversy, these data were included according to the inclusion and exclusion criteria established in this study.

The splenophrenic shunt arises from the splenic vein and terminates in the caudal vena cava cranial to the liver [26]. This type of shunt is congenital in dogs and has a relatively high asymptomatic frequency [14,15,27]. Other studies have described this type of shunt as a left gastro-phrenic shunt [28-30]. In a recent study in the UK on postoperative complications of symptomatic congenital EHPSS in cats, this was the most frequently observed type of shunt [28]. This differs from other surgical studies that demonstrate the highest frequency of left gastric caval shunts but may be related to some extent in that the left gastric vein is involved.

The PV diameter was larger in the CN group than that in the FN group, which could be explained by the difference in body weight between the two groups. The median PV/Ao ratio in group CN had a median value of 1.28 and IQR 1.14–1.35. This value was greater than that reported in previous CT-based studies, a difference that may be attributed to variations in the exact measurement locations and detailed standards [16]. Nevertheless, the PV/Ao ratio in group FN was significantly higher than that in group CN. Thus, the differences in measurements between dogs and cats suggest that separate references are needed for each species.

The mean ±SD PV diameter of group FN was 5.23 ± 0.77 mm and the PV/Ao ratio was 1.46 ± 0.19. These were the PV indices of normal cats established in this study. The PV and Ao diameters in cats demonstrated a moderately positive correlation with body weight; however, this correlation was weaker than that observed in dogs in a US-based study [13]. In the same

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study, no significant correlation between body weight and PV diameter was observed in cats; however, only a weak correlation with Ao diameter was described [13]. These differences may arise from data size. A weak positive correlation was observed between age and the Ao diameter, with no separate analyses conducted in dogs and cats.

Within the feline groups, the PV indices showed significant differences, which followed the order of FN, FA, and FS. The PV/Ao ratio in dogs measured using CT was decreased for all forms of EHPSS [26]. In another study involving asymptomatic dogs with EHPSS, the decrease in the PV/Ao ratio remained within the reference range [14,15]. Conversely, the FA group exhibited the distinctive feature of values outside the established normal index. The symptomatic group had lower values than the other groups for both species. These findings suggest the possibility of differentiating normal, asymptomatic, and symptomatic cats based on PV indices in CT imaging.

The cutoff values between the FN and FS groups were 4.115 mm for PV diameter (sensitivity, 100%; specificity, 97.7%) and 1.170 for PV/Ao ratio (90%, 92.1%), while those between the FA and FS groups were 3.835 mm (90%, 93.8%) and 1.010 (70%, 100%), respectively. A cutoff value of 0.65 for the PV/Ao ratio has been reported based on US in small animals [13]. Similarly, on CT, symptomatic dogs with EHPSS exhibited values below the 0.65 threshold [14], which were lower than those of cats in this study. Considering the species characteristics, these values may be useful for evaluating symptomatic EHPSS. Therefore, symptomatic cats with EHPSS considered normal based on previous index could be correctly classified using these values. The PV diameter demonstrated high diagnostic performance for symptomatic EHPSS in cats, similar to the PV/Ao ratio. This is because cats have a weaker positive correlation with body weight than dogs, and dogs are more affected by variations such as large breeds. Similarly, in US-based studies, the variation in body weight was much lower in cats than in dogs, resulting in minimal weight-related effects [13].

This study had several limitations. First, the retrospective and multicenter design resulted in differences in CT scanner model, exposure factors, and contrast protocols, which may have affected contrast timing and CT image quality. Second, the sample size of the cats was small and may not have been sufficient to form generalized characteristics for disease groups. Third, fasting serum ammonia levels, liver enzyme concentrations, and liver size were not examined in all groups, which may have produced unclear distinctions between the groups. Cases with chronic hepatitis or cirrhosis suspected during imaging evaluation were excluded. However, because histopathological examination of the liver was not conducted, some cases with potential liver diseases may have been included. Finally, although the measurement criteria were adhered to as much as possible, intra- and interobserver agreements were not analyzed. However, previous studies in dogs have shown excellent agreement [16].

In conclusion, the CT results in this study revealed significant differences in PV indices between dogs and cats. Normal values were also established for cats. The PV/Ao ratio demonstrated high diagnostic performance for symptomatic EHPSS, and the PV diameter also performed well.

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