Normal liver-to-heart transit time and shunt fraction after transplenic injection of ^{99M}TC-pertechnetate in healthy cats

Normale lever-naar-hart-transittijd en shuntfractie na transsplenische injectie van ^{99m}Tc-pertechnetaat bij gezonde katten

[1]E. Vandermeulen, [1]K. Peremans, [1]E. Stock, [2]T. Bosmans, [1]M. Hesta, [1]J. Saunders

[1]Department of Medical Imaging of Domestic Animals and Orthopedics of Small Animals, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, B-9820 Merelbeke, Belgium
[2]Department of Small Animals, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, B-9820 Merelbeke, Belgium

E.Vandermeulen@ugent.be

ABSTRACT

Portosystemic shunts (PSS) are rare vascular anomalies in cats. Transsplenic portal scintigraphy (TSPS) can aid in diagnosing PSS in cats. Although the actual performance of the scan remains the same between species, it is questionable whether the generally accepted transit time of seven seconds for small dogs can be applied to cats, thereby influencing shunt fraction (SF) calculation. In this study, normal mean transit time and SF were determined in a population of cats without PSS following two methods established in canine medicine. For both, the mean ± SD transit time was calculated as 6.75 ± 1.58 seconds and 7.40 ± 1.64 seconds respectively, without significant difference between both methods. The results confirmed the validity of the generally used transit time of seven seconds for SF calculation in cats. The average normal SF (± SD) for the cats in this study was 0.73 % (±0.74; range 0.11-2.48%).

SAMENVATTING

Portosystemische shunts (PSS) zijn een zeldzame vasculaire afwijking bij katten. Transsplenische portale scintigrafie (TSPS) kan helpen bij het stellen van de diagnose. Hoewel het uitvoeren van de scan identiek is voor beide species, rees de vraag of de algemeen aanvaarde transittijd van zeven seconden voor kleine honden ook toepasbaar is voor katten. De transittijd heeft een invloed op het berekenen van de shuntfractie (SF). In deze studie werden de normale gemiddelde transittijd en SF berekend bij een groep katten zonder PSS op basis van twee methoden die hiervoor gebruikt worden bij honden. Dit leverde een gemiddelde transittijd (±SD) van respectievelijk 6,75 (±1,58) seconden en 7,40 (±1,64) seconden op. Er was geen significant verschil tussen beide methoden. Dit resultaat bevestigt dat de transittijd van zeven seconden die tot op heden gebruikt wordt om de SF bij katten te berekenen, correct is. De gemiddelde normale SF (±SD) voor de katten in deze studie was 0,73% (±0,74%; spreiding 0,11 - 2,48%).

INLEIDING

Congenital vascular anomalies of the portal system are rare in cats when compared to the prevalence of portosystemic shunts (PSS) in the canine population. Reports of congenital feline PSS in the literature are scarcer and usually comprise case reports with a low number of patients (Blaxter, 1988; Schunk, 1997; Kyles, 2002; Lipscomb, 2007; Tivers, 2011; Palerme, 2013). The most frequently reported type of PSS in cats is a single anomalous extrahepatic connection between the left gastric vein and caudal vena cava, with a lower prevalence of PSS arising from the splenic vein, left gastroepiploic vein or the right gastroduodenal branches (Birchard, 1992; van den Ingh, 1995; Lamb, 1998; Santilli, 2003).

The majority of cats is diagnosed at a young age, although some patients reach adulthood (> one year old) before the disease is detected (Rothuizen, 1982; Scavelli, 1986). Affected cats can present stunted growth and clinical signs are often of neurological nature, such as ptyalism, ataxia, tremor, depression or even seizures (Rothuizen, 1982; Scavelli, 1986, Blaxter, 1988; Birchard, 1992; Havig, 2002; Kyles, 2002; Tillson, 2002). Other (non-neurological) clinical signs are often vague and not specific, either related to the gastrointestinal tract (e.g. vomiting or intermittent anorexia) or the urinary tract (e.g. polyuria, pollakisuria, hematuria, or ammonium urate urolithiasis) (Scavelli, 1986; Havig, 2002; Kyles, 2002; Tillson, 2002;). Congenital heart murmurs (Scavelli 1986; Havig, 2002; Kyles, 2002; Tillson, 2002; Broome 2004) or cryptorchidism (Schunk, 1997; Tillson, 2002) are identified as possible concomitant anomalies, and a relation between copper-colored irises and the presence of an extrahepatic portosystemic shunt is seen but is not pathognomonic (Broome, 2004).

Although the first step in the diagnostic work-up is a blood examination with special attention to indicators of hepatic function, i.e. blood ammonia levels and pre- and postprandial bile acids (Howe, 2002; Tivers, 2011), diagnostic imaging is required for confirmation (Tivers, 2011). Due to its widespread availability, abdominal ultrasonography is the imaging modality of choice in many first-line practices and referral centers. Diagnosis is made by direct visualization of the aberrant vessel or detection of circumstantial signs, such as the decreased size of the portal vein (PV) at the hepatic hilus, turbulent flow in the caudal vena cava, microhepatia, renomegaly and/or urolithiasis (Holt, 1995; Tiemessen, 1995; Lamb, 1996; Lamb, 1998; Lamb, 2002; Santilli, 2003; d'Anjou, 2004, d'Anjou, 2007). The chance of a successful diagnosis rises with increasing experience (Holt, 1995), and with the use of Doppler ultrasound (Lamb, 1996). Transsplenic portal scintigraphy (TSPS) is not a first choice modality but in equivocal ultrasound cases, the presence or absence of a PSS can be confirmed. TSPS

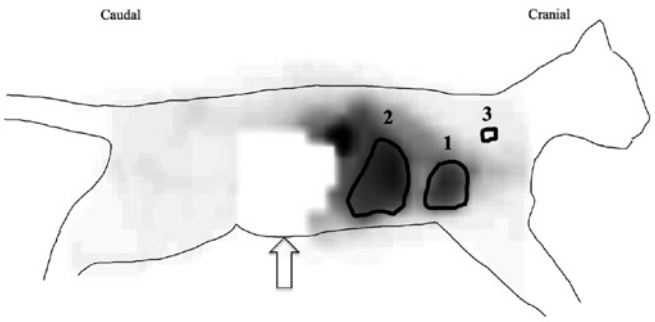

Figure 1. This image is the summation of all 240 frames of the dynamic acquisition. ROI 1 is placed over the heart, ROI 2 over the liver, ROI 3 over the dorsal cervical soft tissue. The injection site in the spleen is masked in post-processing to improve image quality (hollow arrow). A cat-contour is added for clarification (cranial to the right, caudal to the left).

was developed and established in a canine population, and without alteration applied in feline medicine (Cole, 2005; Morandi, 2005; Sura, 2007; Vandermeulen, 2013). While the technical aspects may be identical, the hemodynamics of cats may not be. The shunt fraction (SF) is a quantitative representation of the amount of portal blood flow that bypasses the liver before arriving in the heart, as is the case in a PSS. In patients with normal vasculature, SF will be low, as opposed to patients with a PSS, in which the SF is increased.

The calculation of the SF is based on the transit time of blood between the liver and the heart (Daniel, 1990; Koblik, 1990; Daniel, 1991; Koblik, 1995; Forster-van Hijfte, 1996; Cole, 2005; Morandi, 2005). The aim of the present study was to determine the liver-to-heart transit time in cats with normal hepatic vasculature, based on the methods described earlier for normal dogs (Cole, 2005), as well as to determine the shunt fraction in this normal population. Secondly, the radiation burden is reported, represented by the dose rate in microsievert per hour (µSv/h). The legal parameter for release of patients from the clinic in Belgium is a dose rate below 20 µSv/h at a distance of one meter.

MATERIAL AND METHODS

Patients

Fifteen normal adult cats (European Shorthair), part of the cat colony of the Faculty of Veterinary Medicine, Ghent University (Belgium), were included in the study after approval of the local Ethical Committee (2012/190).

Clinical parameters

One day prior to the portal scintigraphy, a general physical examination of the cats was performed, as well as a cardiopulmonary auscultation. Indirect blood pressure measurement using Doppler signal was obtained (measured at the tail or thoracic limb, depending on the cat's tolerance).

On the fasted patients (food withheld for twelve hours, ad libitum access to water), a 4 mL blood sample was taken via venipuncture of the jugular vein using a 24-gauge needle in order to assess the clinical condition, to evaluate anesthetic safety and to investigate the hepatic function. Standard biochemical and hematological tests were run, extended with preprandial bile acids.

For the postprandial bile acids, the cats were given a meal of a traditional commercially adult cat food, which they were used to consume. One mL blood sample was taken two hours after feeding, similar to the one described above.

During the abdominal ultrasound investigation, a urine sample was taken via cystocentesis using a 22-gauge needle and 5 mL syringe.

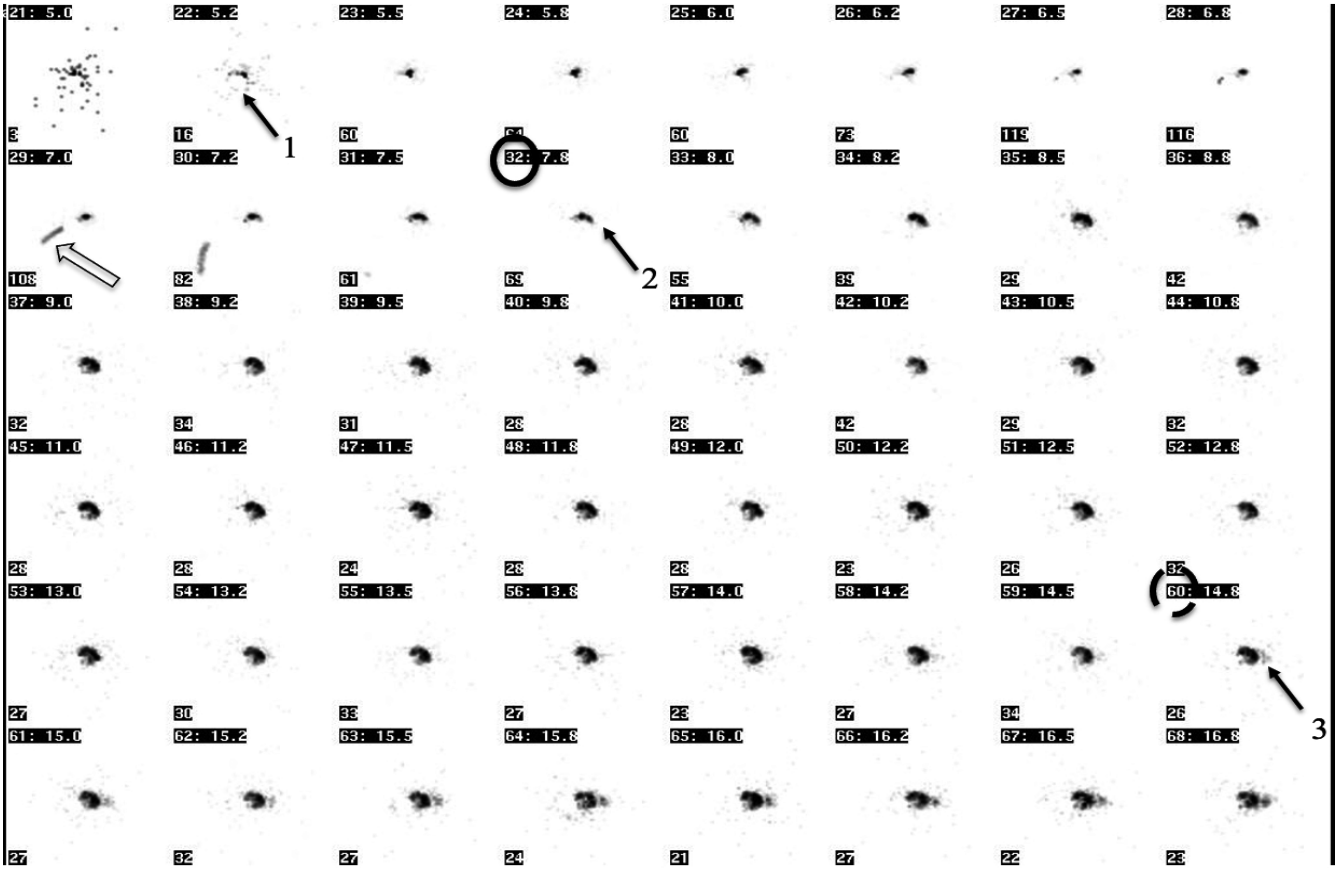

Figure 2. Frame 21-68 (0.25 seconds/frame): starting immediately prior to the injection of the pertechnetate in the spleen (frame 21). Black arrow 1 marks the injection site in the spleen (removed in post-processing to improve image quality). Black arrow 2 indicates arrival of the absorbed pertechnetate in the liver via the portal system, in frame 32 (circled). Black arrow 3 points to the arrival of pertechnetate in the heart via the caudal vena cava, in frame 60 (interrupted circle). The liver-to-heart transit time equals 60 - 32 = 28 frames, or seven- seconds (28 frames / 4 frames per second). The hollow arrow indicates the movement of the syringe used for transsplenic injection away from the patient.

Imaging studies

Abdominal ultrasound

During the twelve-hour fasting period, a full abdominal ultrasound was performed to rule out the presence of vascular or other abnormalities that may influence the results or indicate other health issues. Special attention was given to the measurement of PV/aorta ratio, the presence or absence of abnormal portal vein branches or other aberrant vessels, and secondary signs of PSS, such as decreased hepatic size, increased renal size or the presence of urolithiasis. The ultrasonographic examinations were performed with a 12MHz-linear probe (MyLab30Vet, Esaote Europe B.V., Zaventem, Belgium).

TSPS

To perform the scintigraphic study, the cats were anesthetized using an intravenous bolus injection of propofol to effect (Propovet, 10 mg/mL, Abbott Laboratories, Wavre, Belgium), via an indwelling catheter in the cephalic vein. The cats were then placed in right lateral recumbency above the gamma camera (Toshiba GCA401A), equipped with a low-energy, high-resolution collimator. Under ultrasound guidance, a 22-gauge needle was placed in the splenic parenchyma from a caudoventral approach to avoid overlap with the liver after injection of the radiopharmaceutical and therefore interference with scan processing and interpretation. A shielded syringe containing the small volume of ^{99m}Tc-pertechnetate was coupled to the needle. An average ± SD of 67,0 ± 11,47 megabecquerel (MBq) in a volume of 0.2 ± 0.03 mL was then injected in the splenic parenchyma with continuous ultrasonographic guidance.

A dynamic acquisition protocol was started immediately prior to intrasplenic injection, following a fixed scan protocol (Cole, 2005; Morandi, 2005) that registered 240 image frames over a total duration of one minute (four frames per second). Images were stored in a 128 x 128 x 16 matrix size.

Once the TSPS was performed, the cats recovered from the short anesthesia in dedicated cages in the feline hospitalization ward of the veterinary nuclear medicine department.

Scintigraphic data gathering and processing

Dedicated nuclear medicine software (Hermes Medical Solutions, Stockholm, Sweden) was used to process the acquired image data.

Prior to transit time calculations, individual display of the frames was used to assess the trajectory of the injected radiopharmaceutical after absorption from the splenic parenchyma into the splenic veins.

A summed image of all 240 frames was composed, and a region of interest (ROI) was manually placed over the cardiac region, hepatic region and over the soft tissue in the dorsal cervical region as representation of background soft tissue and circulatory activity (Figure 1).

To assess the transit time between the arrival of the intrasplenic injected activity in the liver and arrival in the heart, the following methods were applied.

Visual assessment

A frame-by-frame analysis was done by scrolling through the individual image frames. The first image frame in which the activity arrived in the liver was noted, as well as the first frame in which the activity arrived in the heart. As each frame lasted 0.25 seconds, the number of frames between arrival in the liver and heart multiplied by 0.25 yields the transit time in seconds between liver and heart (Figure 2).

Quantitative assessment

For each ROI, the number of counts (i.e. incidence of gamma rays arising from this ROI) was depicted in 'list mode' (Figure 3). The frame with a 100%-increase of counts compared to background activity was defined as the frame in which the bolus of radiopharmaceutical arrived in the liver or heart. Identical to the visual assessment, the number of frames between arrival in liver and heart multiplied by 0.25 was consistent with the liver-to-heart transit time(s).

A student's t-test was performed to establish a possible difference between both methods of transit time calculation, with significance set at $p \leq 0.001$.

Based on the established average transit time, the shunt fraction was calculated. For this, the activity in the cardiac ROI during a predetermined time period (i.e. the liver-to-heart transit time) was summed, and divided by the summed activity in the cardiac ROI plus the summed activity in the liver ROI for the same time period. To obtain a percentage, this value was then multiplied by 100. The liver-to-heart transit time used for the calculation was determined in the first part of the study.

The SF formula is as follows (with n = liver-to-heart transit time):

$$Shunt\ fraction\ (\%) = (\sum_{n} cardiac\ activity\ / (\sum_{n} cardiac\ activity + \sum_{n}^{'} hepatic\ activity)) \times 100$$

Dose rate measurement

The dose rate was measured using a handheld Geiger-Müller counter (Radiagem ™ 2000, Mirion Technologies (MGPI) SAS, Lamanon, France), immediately after completion of the scan and 24 hours after the scan. The dose rate was recorded at two locations: at the level of the injection site in the spleen, and at one meter distance from the patient. The highest amount of remaining activity was assumed to be registered at the level of the injection site: approximately 50% of the injected dose is absorbed rapidly from the spleen into the blood stream, the remaining 50% remains temporarily in the splenic parenchyma and is absorbed more slowly into the blood stream (Cole, 2005). The activity at one meter distance was measured as this is the Belgian legal parameter for patient discharge. All dose rates were recorded in µSv/h.

RESULTS

Demographical data

The average age of the European Shorthairs at the date of the study was 40 ± 13.7 months (range: 20 months – 64.8 months) and there were ten females and five males (one intact female and two intact males). The average weight was 3.5 ± 0.95 kg (range: 2.4 – 5.0 kg).

Clinical parameters

For all cats, the clinical parameters were unremarkable and auscultation of the heart and lungs was normal. None of the cats showed abnormalities on the general hematological and biochemical blood examinations.

The preprandial bile acids for twelve cats were <1 µmol/L, for three cats they were 2, 3 and 4 µmol/L, respectively, all well below the upper limit of 10 µmol/L. Postprandial bile acids were higher than the preprandial values in all cats as expected, but all remained under 10 µmol/L (average 6.7 ± 1.59 µmol/L, range 4-9), and corresponded to the reported postprandial values of 8.3 ± 0.3 µmol/L for normal cats (Center, 1995; Webster, 2009).

Routine urinalysis was performed, determining urinary specific gravity, proteinuria and the presence of cellular material. With the exception of a trace amount of proteinuria in two cats, the findings were unremarkable.

Ultrasonographic findings

As there are no objective measurements to evaluate hepatic size, subjective interpretation was done. For all cats in the study, this was deemed normal.

The average ± SD values of the PV/Ao ratio was 0.97 ± 0.10 (range 0.90 – 1.15) and this falls within the normal range established for cats (0.78–1.25, average 0.93 (d'Anjou, 2004)), thereby excluding the presence of a macroscopic PSS, either intrahepatic or extrahepatic.

No renomegaly was noted, the average ± SD size was 3.64 ± 0.30 cm for the left kidney and 3.74 ± 0.39 cm for the right kidney (range left: 3.28 – 4.28 cm and right: 3.32 – 4.35 cm), all within the normal range reported for cats (d'Anjou, 2015).

Urolithiasis or nephrolithiasis were not seen in any of the cats.

TSPS

All injections were successful on first trial. The cinematic display of the scans showed arrival of the absorbed radiopharmaceutical in the liver before progressing to the heart, thereby confirming the absence of abnormal vasculature of the portal system cranially to the connection of the splenic vein to the PV. Absorbed ^{99m}Tc-pertechnetate was transported via the blood stream into the splenic vein and thereafter to the portal vein, thus arriving in the liver. Later, the hepatic venous blood gathered into the caudal vena cava and arrived in the right atrium of the heart.

Visual assessment of the transit time from liver to heart yielded an average ± SD of 6.75 ± 1.58 seconds. When based on the listed data, the transit time was 7.40 ± 1.64 seconds. The range of transit times was equal for both methods: 5.25 to 9.25 seconds. If there was a difference between both transit times for each individual cat, the visual transit time was generally slightly shorter that the transit time derived from listed data. However, this did not result in a significantly different transit time for the entire group ($p = 0.07$).

The average ± SD shunt fraction for this group of cats was 0.73 + 0.736 % (range 0.11 – 2.48 %), calculated with a seven-second transit time. The low SF in normal cats is due to the appearance of cardiac activity in only a few of the 28 frames that are included in the seven-second period for calculation, whereas liver activity is present in all frames.

Dose rate

The dose rate at the injection site immediately after the scan was logically the highest (234.4 ±86.67 µSv/h). The rapid physical decay (the physical half-life of ^{99m}Tc is approximately six hours) combined with further absorption from the injection site already provided a much lower dose rate at the injection site 24 hours later (5.99 ± 2,63 µSv/h). At a distance of one meter from the patient, the dose rate was much lower both immediately after the scan and 24 hours later: 1.95 ± 0.89 µSv/h and 0.57 ± 0.24 µSv/h, respectively.

DISCUSSION

Transsplenic portal scintigraphy can be an adjuvant imaging tool when abdominal ultrasound is not diagnostic. The aim of this study was to investigate the transferability of the SF formula derived from a TSPS scan from dogs to cats. The SF determines the amount of injected activity that bypasses the liver via an aberrant blood vessel (i.e. the portosystemic shunt) after

Point	Start	Length	Roi 1	Roi 2	
1	1.0	0.2	0.0000	2.000	
2	2.0	0.2	0.0000	1.0000	
3	3.0	0.2	0.0000	0.0000	
4	4.0	0.2	0.0000	2.000	
5	5.0	0.2	0.0000	0.0000	
6	6.0	0.2	0.0000	1.0000	
7	7.0	0.2	0.0000	0.0000	
8	8.0	0.2	0.0000	0.0000	
9	9.0	0.2	0.0000	2.000	
10	10.0	0.2	0.0000	1.0000	
11	11.0	0.2	0.0000	0.0000	
12	12.0	0.2	0.0000	1.0000	
13	13.0	0.2	0.0000	0.0000	
14	14.0	0.2	0.0000	4.000	Arrival in liver
15	15.0	0.2	0.0000	5.000	
16	16.0	0.2	0.0000	8.000	
17	17.0	0.2	0.0000	10.000	
18	18.0	0.2	0.0000	2.000	
19	19.0	0.2	0.0000	2.000	
20	20.0	0.2	0.0000	8.000	
21	21.0	0.2	0.0000	12.00	
22	22.0	0.2	0.0000	39.00	
23	23.0	0.2	0.0000	89.00	
24	24.0	0.2	0.0000	139.0	
25	25.0	0.2	0.0000	162.0	
26	26.0	0.2	0.0000	207.0	
27	27.0	0.2	1.0000	219.0	
28	28.0	0.2	0.0000	231.0	
29	29.0	0.2	0.0000	197.0	
30	30.0	0.2	0.0000	220.0	
31	31.0	0.2	0.0000	257.0	
32	32.0	0.2	1.0000	291.0	
33	33.0	0.2	1.0000	323.0	
34	34.0	0.2	0.0000	326.0	
35	35.0	0.2	2.000	345.0	
36	36.0	0.2	0.0000	348.0	
37	37.0	0.2	0.0000	356.0	
38	38.0	0.2	2.000	373.0	
39	39.0	0.2	0.0000	344.0	
40	40.0	0.2	0.0000	387.0	
41	41.0	0.2	0.0000	381.0	
42	42.0	0.2	0.0000	366.0	
43	43.0	0.2	0.0000	344.0	
44	44.0	0.2	0.0000	342.0	
45	45.0	0.2	0.0000	374.0	
46	46.0	0.2	3.000	346.0	Arrival in heart
47	47.0	0.2	2.000	380.0	
48	48.0	0.2	4.000	374.0	
49	49.0	0.2	8.000	420.0	
50	50.0	0.2	12.00	353.0	
51	51.0	0.2	9.000	395.0	
52	52.0	0.2	18.00	386.0	
53	53.0	0.2	26.00	316.0	
54	54.0	0.2	35.00	353.0	
55	55.0	0.2	36.00	355.0	
56	56.0	0.2	50.00	319.0	
57	57.0	0.2	47.00	301.0	
58	58.0	0.2	44.00	294.0	
59	59.0	0.2	69.00	311.0	
60	60.0	0.2	80.00	314.0	

Figure 3. Example of a part of the list-mode data as used for the quantitative assessment of liver-to-heart transit time. 'Point' and 'Start' indicate the frame number, 'Length' is frame duration (0.25 seconds - automatically abbreviated to '0.2'), 'ROI 1' and 'ROI 2' represent the amount of pertechnetate in the heart (ROI 1) and liver (ROI 2) per individual frame. Arrival of the activity in the liver occurs at point 14, arrival in the heart at point 46, yielding a transit time of (46 - 14) / 4 = 8 seconds.

ultrasound-guided, intrasplenic deposition of a small bolus of ^{99m}Tc-pertechnetate (Cole, 2005; Morandi, 2005; Vandermeulen, 2013). Its calculation is based on the transit time of blood between the liver and the heart (Daniel, 1990; Koblik, 1990; Daniel 1991; Koblik, 1995; Forster-van Hijfte, 1996; Cole, 2005; Morandi, 2005). Initially, portal scintigraphy relied on the per rectal deposition of a small amount of ^{99m}Tc-pertechnetate (per rectal portal scintigraphy or PRPS), after which the absorbed radiopharmaceutical is transported to the PV, liver, hepatic veins, caudal vena cava and then the heart. This procedure was developed in the early 1990's and the average transit time was set at twelve seconds (Daniel, 1990; Koblik, 1990; Daniel, 1991; Koblik, 1995; Forster-Van Hijfte, 1996). The PRPS technique was later modified into TSPS to decrease the amount of radiopharmaceutical needed for the evaluation of the portal system. Because of the higher absorption of the injected activity (15% for PRPS, 50% for TSPS), the transsplenic approach requires a lower amount of radiopharmaceutical, and yields qualitatively better scans (Cole, 2005; Morandi, 2005; Sura, 2007; Morandi, 2010; Vandermeulen, 2013). Due to the different location of radiopharmaceutical deposition, the shunt fraction needed to be revised, which was done in a population of young beagles: a transit time of seven seconds was established. Thereafter, these seven seconds have been widely accepted for canine and feline patients (Cole, 2005; Morandi, 2005; Sura, 2007; Vandermeulen, 2013).

However, the increasing awareness of possible differences between cats and dogs lies at the base of this study, which aimed to investigate if the seven-second transit time, established in a canine population, is valid for feline patients. Inspired by the calculation methods by Cole (2005), in this study, the average transit time was calculated using visual assessment of the scans and secondly, using the listed data. This resulted in an average transit time of 6.75 ± 1.58 seconds for the visual method, and 7.4 ± 1.64 seconds for the list-data method. The range of transit times was an identical range for both: 5.25 - 9.25 seconds. This finding confirms the validity of previous studies, in which the seven-second transit time was applied to TSPS of feline patients.

The normal SF for this group of cats, using this seven-second transit time and based on the visual arrival of the injected activity in the liver ROI, was 0.73 + 0.74 % (range 0.11 – 2.48 %). Compared to the SF obtained for dogs using the same calculation method, the normal average and range are mildly lower: Cole et al. (2005) reported an average + SD of 2.6 + 1.3 % (range: 0.8 – 4.3%). However similar, there is no clear explanation for this mild discrepancy between dogs and cats. Despite the mild discrepancy, these values can however be considered identical for normal cats and dogs. Indeed, due to the small value, one frame more or less with the appearance of cardiac activity can change the SF. This is reflected in the relatively wide normal range. Although the exact SF value is of little interest in normal cats (a SF value within the normal range with a normal visual assessment is sufficient to confirm normalcy), the SF can be of great value in patients with abnormal or collateral portal circulation. An increase in SF will be seen, together with a larger number of frames within the seven-second period with cardiac activity, due to earlier arrival via the shunting vessel(s).

The choice to perform a TSPS is only done after inconclusive results of the ultrasonographic examination. Nowadays, there is a wide range of advanced imaging techniques at our disposal. Computed tomographic angiography (CTA) gains importance as it gives detailed information of the abdominal blood vessels (Echandi, 2007; Zwingenberger, 2009; Brown, 2010), and even magnetic resonance angiography (MRA) has been reported in veterinary medicine (Seguin, 1999; Bruehschwein, 2010). Despite the limited number of veterinary nuclear medicine centers, scintigraphic techniques have been widely studied since the early 1990's and have been successfully used in clinical practice to diagnose PSS since then. Not only can it rapidly confirm the presence of an extraphepatic macroscopic portosystemic shunt, it also gives an indication of the morphology of the ending of the shunt, i.e. the connection to the azygos vein, the caudal vena cava or internal thoracic vein can be distinguished (Morandi, 2005; Morandi, 2007).

A disadvantage is the use of radiopharmaceuticals. The ALARA principle dictates sensible use of radioactivity in (veterinary) medicine. The low activity that is injected (67.0 ± 11.47 MBq) together with the short half-life of ^{99m}Tc-pertechnetate (physical half-life of ± six hours, decay via low-energy gamma radiation) only gives a relatively low radiation burden for the patient and its owner. The Belgian legal dose rate limit below which the measured dose rate needs to be for safe release, is set at 20 µSv/h at a distance of one meter, a threshold that is not even reached immediately after the injection. At a distance of one meter from the patient, the dose rate is much lower both immediately after the scan and 24 hours later: 1.95 ± 0.89 µSv/h and 0.57 ± 0.24 µSv/h.

There are some limitations to be noted in this study. Firstly, the age at which a PSS is diagnosed is usually younger than the age of the cats included in this study. As this study was performed with cats that resided in the cat colony of the Faculty of Veterinary Medicine and because this colony only consists of adult cats, this was an unavoidable difficulty. Although a wide age range for the diagnosis of PSS in cats has been reported in the literature (which is often not made until the patient reaches adulthood), the results of the present study are deemed to be valid (Blaxter, 1988; Forster-van Hijfte, 1996; White, 1996; Havig, 2002; Kyles, 2002; Palerme, 2013; Vandermeulen, 2013; Valiente, 2020). Later diagnosis is more often seen when a portoazygos or -hemiazygos shunt rather than a portocaval shunt is present (Rothuizen, 1982; Martin, 1993; Kyles, 2002).

A potential indicator for the presence of an extrahepatic PSS is the alteration of the portal blood flow velocity and the direction on Doppler investigation. Hepatofugal flow, the consequence of lower flow resistance through the shunting vessel, or irregular flow velocity in the PV, could increase confidence to identify the presence of an extrahepatic PSS (d'Anjou, 2004). In this study, the portal vasculature was thoroughly examined, including Doppler investigation. Absence of reversed flow direction or turbulence on Doppler investigation was seen in all cats. Unfortunately, the PV flow velocity was not measured, although it could be beneficial in the search to diagnose PSS.

A limiting factor of TSPS is the requirement of a veterinary nuclear medicine facility, the presence of trained and licensed personnel and the use of radioactive isotopes. However, if available, it is a fast and solid method to confirm the presence of a macroscopic PSS (either intra- or extrahepatic). As with many ultrasound-based methods, the technique requires a learning curve to familiarize the operator with the injection in the splenic parenchyma. Indeed, the main cause of a nondiagnostic scan is the deposition of the radiopharmaceutical into the peritoneal cavity, as intrasplenic injection may be challenging in the small-sized feline spleen. Although this does not give a diagnostic scan, the low amount of radioactivity does not have negative consequences for the patient.

CONCLUSION

The seven-second transit time, as it has previously been applied in the calculation of a SF in cats, is consolidated in this study. TSPS is a rapid imaging method in the diagnostic work-up of patients suspected of PSS. The low activity that is injected, allows this technique to be performed on an out-patient base, provided the owner is given radioprotective measures prior to the scan in order to limit exposure as much as possible.

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