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# Prevalence of polydipsia in dogs with pericardial effusion and cardiac tamponade

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# 1. Abstract

Pericardial effusion is an abnormal accumulation of fluid in the pericardial sac, which may eventually lead to a significant increase in intrapericardial pressure and cardiac tamponade, a life-threatening condition characterized by collapse of the cardiac chambers and heart failure. A variety of clinical signs can be reported by the owner of dogs presenting with pericardial effusion and cardiac tamponade; most of these are non-specific, including polydipsia.
This research project consisted of a retrospective and a prospective study. Clinical signs reported by the owner of dogs presenting with cardiac tamponade due to pericardial effusion and physical examination findings at presentation were evaluated. The prevalence of polydipsia was calculated, next to that of other clinical signs and physical examination findings. The presence of a mass on echocardiography and the amount of fluid drained from the pericardium were also assessed, and their correlation with the presence of polydipsia was investigated.
A total prevalence of 35% for polydipsia was found. There was no significant association between this and the presence of a mass or ascites. The amount of fluid drained from the pericardium did not seem correlated with the presence of polydipsia.
The prevalence of polydipsia in this study is higher than previously reported and can occur at first presentation or relapse. Therefore, it could potentially be useful as a sign of recurrence that owners can monitor at home.

## 2. Table of content

## 3. Abbreviations

PE = pericardial effusion
CT = cardiac tamponade
PP = pulsus paradoxus
AVP = arginine vasopressin
AngII = angiotensin II
ADH = anti diuretic hormone
ANH = natriuretic hormone

# 4. Introduction

Pericardial effusion (PE) is the most common disease of the pericardium in dogs and is defined as an abnormal accumulation of fluid in the pericardial sac.[1] It has a reported prevalence of 0.3% in the canine population examined at a referral hospital and up to 7% in dogs with clinical signs of cardiac disease.[2] Small amounts of fluid may not cause clinical signs. However, as the volume and pressure in the pericardial space increase, a life-threatening condition called cardiac tamponade (CT) can occur,[3] as explained in detail later in the text.

*Anatomy of the pericardium*

The pericardium consists of an outermost fibrous part and an inner and outer serous part. The inner serous part of the pericardium is attached to the heart wall and is also known as the visceral layer. It covers the myocardium, the coronary vessels, and the fat on the heart surface. The pericardial cavity lies between the parietal and visceral layers of the serous pericardium.[4] Normally, this cavity is filled with 1-15ml of fluid, which is an ultrafiltrate of blood serum.[5] Pericardial fluid is removed into the lymphatic system and with its lymphocytes plays a role in protecting the heart from pathogens.[6,7] The pericardium itself has multiple functions, including but not limited to: preventing excessive motion of the heart in the thorax without complete fixation, isolating the heart from other structures in the thorax preventing extension of infection or neoplasia to the heart, enhancing ventricular interaction, and limiting acute cardiac dilations.[5,8]

*Causes of pericardial effusion*

In PE, there is an abnormal accumulation of fluid in the pericardial sac. This phenomenon is linked to a variety of diseases. The most common etiologies in dogs are neoplastic or idiopathic PE. Hemangiosarcoma, heart base tumors, and mesothelioma are the most common neoplastic causes. A few examples of non-neoplastic causes are infections, congestive heart failure, atrial rupture, hypoproteinemia, and coagulopathy.[9]

The accumulation of fluid could be due to an increase in the production of pericardial fluid, e.g. in case of infection, or due to a decrease in reabsorption of pericardial fluid, e.g. in case of congestive heart failure.[7,10] Determining the cause of the PE is essential as it provides information for appropriate treatment, clinical progression, and prognosis. Dogs with PE secondary to neoplastic causes often have a worse prognosis than dogs with PE secondary to non-neoplastic causes.[11] One study found a median survival time of 1068 days where no mass was seen on echocardiography, whereas in the presence of a mass the median survival time was 26 days.[9]

*Cardiac tamponade*

Regardless of the cause, when fluid accumulates in the pericardial space, the ability of the pericardium to stretch may eventually be exceeded. This results in increased intrapericardial pressure.[1] The rate at which the intrapericardial pressure rises depends on multiple factors. First of all, the physical characteristics of the pericardium have to be taken into account. The capacity to stretch of normal pericardial tissue varies among dogs.[12] Additionally, the rate of the fluid effusion and the volume of the fluid also have to be considered. Small volumes that accumulate rapidly can result in a significant rise in intrapericardial pressure, whereas large volumes that accumulate slowly can result in small rises in pressure.[3] In some cases, the intrapericardial pressure will approach the pressure in the right atrium and, eventually, ventricle.[13] In this case, there will be a negative transmural pressure gradient during early diastole between the right atrium and possibly ventricle cavity and the pericardial space, which results in collapse of these cardiac chambers.[14]

Cardiac tamponade is commonly confirmed by echocardiogram by the finding of PE and the above-mentioned collapse of the right atrium and/or ventricle, which is mostly seen during early diastole, in the presence of compatible clinical signs, as outlined below.[1] The right side of the heart is more prone to collapse than the left side due to a thinner wall and lower pressures in its chambers. However, not only the filling of the right heart is reduced. Diastolic filling in the left ventricle is also reduced due to reduced pulmonary venous return as a result of decreased right heart output and shift of the interventricular septum towards the left due to increased right ventricular pressures.[15,16] As the diastolic filling of the heart is compromised and the preload is reduced, as well as the Frank-Starling mechanism, cardiac output and ultimately arterial blood pressure decrease.[8,17]
The pressure driving venous return in normal circumstances is a result of a decrease in intrathoracic pressure during inspiration and an increase in intra-abdominal pressure as a result of descent of the diaphragm. Under pathological circumstances as CT, the volume of blood returning from the systemic circulation cannot be accommodated by the right atrium during diastole. Subsequently, right atrial pressure will increase and result in systemic venous congestion.[18]

*Clinical presentation*
Most of the clinical signs reported by the owner of dogs presenting with CT are nonspecific, including for example lethargy or exercise intolerance.[9,19] Sometimes collapse, dyspnea, coughing, anorexia, vomiting, and polydipsia are reported.[9,11] Coughing as a symptom of PE is poorly understood, but may be a result of the pressure of the distended pericardial sac on the airways.[19] Two different mechanisms are proposed as to why vomiting may occur: direct irritation of the phrenic nerve or as a result of decreased perfusion of the gastrointestinal tract. Both mechanisms, however, are not proven.[20]

A combination of findings at physical examination is highly indicative of PE with CT. These include muffled heart sounds, weak pulses, abdominal distention due to ascites, and jugular venous distention.[9,19]
Clinical findings consistent with reduced cardiac output are most often seen when acute CT is present.[21] These include prostration, lowered systemic blood pressure, tachycardia, prolonged capillary refill time, cool extremities, and sometimes peripheral cyanosis.[18]
Some clinical findings have prognostic value. Collapse, absence of ascites, and presence of a mass on echocardiography are proven to be negative prognostic indicators.[9,22]

Another finding at physical examination that is highly indicative but not specific of CT, is a pulsus paradoxus. This is an exaggeration of the normal, physiological fall in blood pressure during inspiration.[23] During expiration there is relatively less blood flow to the right ventricle and more to the left ventricle and thus systemic blood pressure is higher. The physiological decrease is caused by reduced left ventricular stroke volume.[23] Two mechanisms can explain this phenomenon.[16] During inspiration, the chest and diaphragm expand, which increases negative pleural pressure. As a result, more blood flows to the pulmonary vascular system with its expanded compliant capillaries, and less to the left ventricle, as the total volume is fixed.[8,16,23] Additionally, the ventricular septum shifts more towards the left ventricle because of the increased right ventricular end-diastolic volume. Because the left ventricle is reduced in size, left ventricular stroke volume is further reduced.[16]
It has been found that despite CT, filling of the right atrium still increases during inspiration. Since the right heart cannot expand to the lateral side, it interferes with filling of the left heart. This is made possible by an exaggerated leftward shift of the ventricular septum [24].

*Polydipsia and cardiac tamponade*

Polydipsia is characterized by an increased water intake. One retrospective study found that 12% of dogs with PE presented with polydipsia.[9]

Thirst is essential for the body fluid homeostasis, and is stimulated by increases in blood osmolarity and/or decreases in blood volume or hypotension.[25] During CT, blood osmolarity remains constant. Blood pressure, however, decreases when cardiac output is reduced.[26] Hypotension stimulates thirst via two sets of receptors; low-pressure cardiopulmonary receptors in the atria, pulmonary artery, and vena cava and high-pressure baroreceptors in the walls of the aortic arch and carotid sinus. The cardio-pulmonary receptors detect blood volume, whereas the baroreceptors measure arterial pressure.[25] A detection of hypovolemia or hypotension results in arginine vasopressin (AVP) secretion and an increase in thirst.[27]

Arginine vasopressin is released from the posterior neurohypophysis into the bloodstream. In the kidney, it stimulates water uptake via aquaporin 2 in the collecting duct cells, hence reducing water loss. It also induces vasoconstriction via receptors in the vasculature.[28] Although AVP itself does not increase thirst, the threshold for thirst and AVP release seems to be identical.[28] One study, however, did find a lowered thirst threshold when AVP levels are increased.[29]

Alongside AVP, renin is released in response to the decreased perfusion pressure perceived by the juxtaglomerular apparatus in the kidneys.[28,30] Renin causes the generation of angiotensin II (AngII). Angiotensin II leads to vasoconstriction, an increase in thirst, and release of aldosterone. Aldosterone is a mineralocorticoid hormone released by the adrenals. Aldosterone increases sodium absorption in the kidney, and thus increases water uptake. It also increases sodium appetite.[28]

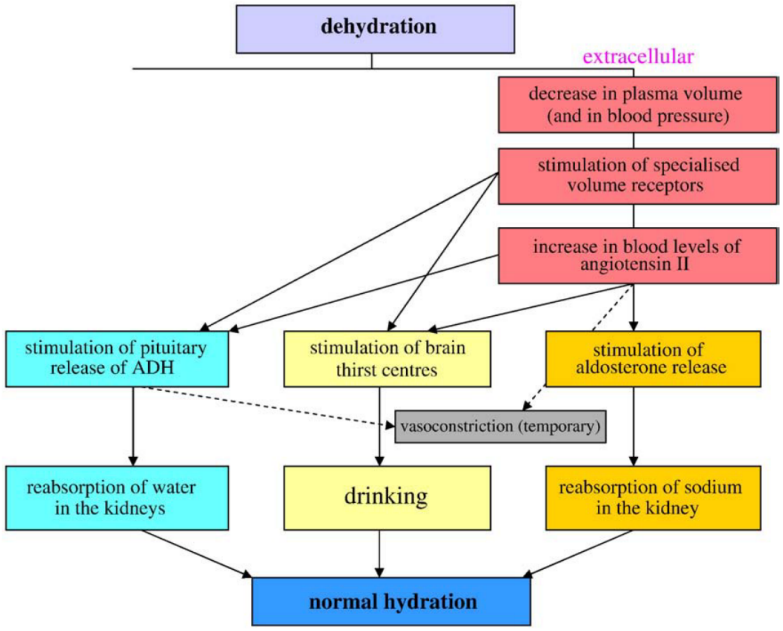


**Figure 1.** Hydration mechanism during a decrease in blood pressure. Anti diuretic hormone (ADH) is also known as arginine vasopressin.
*Figure adapted from Thornton (2010)*[28]

The different hormones released in the context of CT, which could be related to the increase in thirst, have been studied by various authors in an experimental setting.[17,26,31,32] During acute induced CT in dogs, the excretion of AVP is increased, most likely as a response to the decreased output. This would be confirmed by the quick decline of AVP levels after pericardiocentesis.[26,32] Furthermore, a rise in plasma renin levels and a generation of AngII is

seen during CT, when arterial blood pressure falls by 30%.[31,32] This observation seems to be in contrast with another study, which showed that renal blood flow is preserved in the conscious dog despite a drop in cardiac output up to 66%.[17] Nevertheless, it appears that there are multiple complex mechanisms behind hemodynamics during CT, which are not yet fully understood.

Natriuretic hormone (ANH) has also been investigated in the above-mentioned studies. Although it is not directly linked to thirst, it does play an important role in the water homeostasis of the body. Natriuretic hormone is released by the heart and induces vasodilatation, increases glomerular filtration rate in the kidney, and inhibits aldosterone secretion.[33] It has been demonstrated that ANH levels remain constant during CT, but also that drainage of the pericardial sac results in a sudden increase in ANH levels. This rise seems to be the result of atrial stretch resulting from restored filling after pericardiocentesis.[26,32,34] Interestingly, in one study, dogs produced a significant amount of urine following pericardiocentesis.[26]

*Treatment*

Cardiac tamponade is a life-threatening condition. Upon diagnosis, a lifesaving procedure is recommended: pericardiocentesis, through which the PE is drained with a needle or catheter. This procedure has a relatively low complication rate, with the most reported adverse effect being triggering cardiac arrhythmia. However, with guidance of image modalities, this may be prevented.[13] Although analysis of pericardial fluid appears to be of little diagnostic utility in most cases, cytological analysis is routinely performed as it can occasionally provide important information about the underlying cause.[35–37] One study found an overall diagnostic utility of 7,7% up to 20.3% depending on the hematocrit of the sample.[37]

Due to its low complication rate and being a life-saving treatment, pericardiocentesis is the treatment of choice in the emergency setting. However, risk of recurrence of PE and thus CT is present after the procedure.[38] One study found a relapse of 64% in dogs with a non-neoplastic cause and in all dogs with a neoplastic cause, stressing the importance of close monitoring of clinical signs that could point towards a recurrence of PE.[9] Many dogs can be treated with pericardiocentesis alone. However, when PE recurs after one or multiple pericardiocenteses, pericardiectomy is recommended, unless a negative prognosis is present, such as in cases of highly suspected hemangiosarcomas.[11,39]

Next to the above, aimed at treating PE and CT, therapy for the underlying condition is desirable, when possible. Chances of relapse remain up to 64%, regardless of the underlying condition.[9]

# 5. Materials and Methods

This research project consisted of two parts: a retrospective study and a prospective study. The retrospective study included data retrieved from files of patients examined in the past ten years, while the prospective study included dogs presenting during the four months of this research project.

For both parts, the study population was comprised of dogs referred to the Veterinary Teaching Hospital of Utrecht University for diagnostic investigation and treatment of suspected PE with CT. The dogs had to be referred by a veterinarian due to the presence of clinical signs compatible with CT. The PE with CT had then to be confirmed at the Veterinary Teaching Hospital of Utrecht University through physical examination and echocardiography. Dogs were excluded from this study in absence of a comprehensive or reliable anamnesis and when pericardiocentesis was already performed by the referring veterinarian.

*Retrospective study*
The case files of all dogs diagnosed with PE between January 2011 and February 2021 were identified through examination of a record of cases, organized per diagnosis, held by the Cardiology department. After this initial search, the file of each dog was evaluated individually to determine if the inclusion criteria were met. The signalment, presence or absence of polydipsia (based on the client perception/subjective observation of significantly increased thirst), presence of other clinical signs reported by the owners, and current co-morbidities and medications (both cardiac and non-cardiac) were recorded. The files were then evaluated for findings at physical exam, blood pressure measurement, and echocardiography. The data were noted on a standard capture form, which can be found in Appendix 1. When a file failed to mention the absence or presence of a clinical sign, this was marked as not present.

*Prospective study*
Dogs presented between February 2021 and May 2021 were included in the prospective part of this study. Recurrence episodes were only analyzed for the presence of polydipsia. Full clinical history from clients was obtained by attending clinicians on the same day as the diagnostic or therapeutic procedures were undertaken. These clinicians work in the emergency or cardiology service, both involved in the care of the subjects included. Signalment, the presence or absence of polydipsia (based on the client perception/subjective observation of significantly increased thirst) within 48 hours prior to presentation, the presence of other presenting clinical signs detected by the owners, and current co-morbidities and medications (both cardiac and non-cardiac) that the dog was receiving at that moment were recorded on the same data capture form as for the retrospective study.
All patients underwent a routine physical examination. The patients' weight was recorded. Blood pressure was measured indirectly, if possible, by oscillometric or Doppler devices with an appropriately sized cuff placed on a limb or tail. Echocardiography was performed on dogs positioned standing and/or in right lateral and/or left lateral recumbencies by board-certified specialists in veterinary cardiology, or by supervised residents. Pericardial effusion and echocardiographic signs of CT (right atrial collapse ± right ventricular collapse, vena caval distension, hepatic venous congestion, peritoneal/pleural effusion) were confirmed. Dogs were also echocardiographically screened for the presence of cardiac masses.

*Statistical analysis*
The data was first entered in Excel and then exported to SPSS version 26 and analyzed. Descriptive statistical analysis was performed in all patients, using the mean with standard

deviation, and median with a given range, depending on the distribution and presence of outliers. A binary logistic regression was used to predict the likelihood that the reported presence of polydipsia was related to the presence of a mass or ascites. A Fisher's Exact Test was used to establish whether an association between polydipsia and the use of furosemide was present. To investigate differences between dogs with and without polydipsia that could possibly relate to the volume of fluid drained from the pericardium, a Mann-Whitney *U* Test was used. The amount of fluid was first corrected for the bodyweight of the dog. Cases where the pericardial fluid drained into the pleural space during pericardiocentesis, or if pleural effusion was reported as drained simultaneously, were excluded from this analysis. An alpha level of 0.05 was used for all statistical tests.

# 6. Results

*Retrospective study*

*Signalment*

During the years that the study covered, 56 dogs met the inclusion criteria. The mean weight was 30 kg ($s$ = 16 kg) and the mean age at the time of the first visitation was 8 years ($s$ = 3 years).

The most affected breed in this study was the Labrador Retriever with 10 subjects represented. The different breeds in this population and their prevalence are presented in Table 1, which can be found in Appendix 2. Twenty-seven dogs were neutered females, two dogs were intact females, ten dogs were neutered males, and sixteen dogs were intact males.

*Evolution*

Eleven dogs were euthanized at first visitation due to a poor prognosis.

Among the rest, thirteen dogs experienced recurrence of the condition, as confirmed by physical exam and echocardiography, and one of them had two episodes of recurrence. For seven additional dogs, recurrence was reported, but no sufficient data regarding anamnesis, physical exam, and/or echocardiography were available, for which their recurrence visits were excluded from further analysis. The median time between the first visit and recurrence for the 13 dogs with confirmed relapse was 46 days, with a range from 5 days to 11 months.

*Clinical signs reported by the owner*

The most common clinical signs described during anamnesis, regardless of whether the dog was presented for the first time or due to recurrence, were lethargy (76%), anorexia (67%), and exercise intolerance (55%). When focusing on the first visit, these remain the most common clinical signs. However, percentages changed slightly when only looking at recurrence visits, with lethargy (64%) and exercise intolerance (64%) still being the most frequent presenting signs, followed by dyspnea (50%) and polydipsia (50%). The prevalence of the presenting signs per visit are listed in detail in Figure 2.

Polydipsia was reported in 26 out of the 70 cases in total (37%). For the first visitation, polydipsia was reported in 19 out of 56 cases (34%), and for recurrence visits polydipsia was reported in 7 out of 14 cases (50%).

More specifically, among the dogs that had a confirmed relapse of PE with CT, four presented polydipsia at first presentation and recurrence, one only at first presentation, and two only at recurrence; the dog with three episodes of PE with CT showed polydipsia only near the time of the first relapse.

*Physical examination findings*

Weak pulse and muffled heart sounds were the most reported abnormalities identified during physical examination by the attending clinician, both at the time of the first diagnosis and when looking at the total number of visits. When looking at recurrence alone, ascites (71%) and muffled heart sounds (71%) were mostly observed. Dyspnea was the least commonly observed abnormality both at the time of first diagnosis and recurrence. These findings are reported in Figure 3. Blood pressure as well as multiple other physical examination findings were left out for further analyses as only a few results were available.

*Statistical analysis*

Regarding the logistic regression, the Hosmer and Lemeshow test indicated the data were appropriate for analyses [$\chi 2(2) = 3.879$, $p = 0.144$].

There was no significant association between polydipsia and the presence of a mass or ascites ($p$=0,508 and $p$=0.808). The use of furosemide and the presence of polydipsia were also not significantly associated (p = 0.277).
The Mann-Whitney *U* Test did not identify significant differences in the amount of fluid drained from dogs presenting with polydipsia, and dogs for which polydipsia was not reported by the owner (U = 85.000, z = -0.400 $p$ = 0.689).

*Prospective study*
*Signalment*
Seven dogs were included in the prospective part of the study: two Labrador Retrievers, one Belgian Shepherd, one Small Münsterländer, one Golden Retriever, one Beagle, and one mixed breed dog. There were four neutered males, two neutered females, and one intact male. The mean age was 11 years ($s$ = 3) old. The mean weight was 30kg ($s$ = 9.5).

*Evolution*
Four of the dogs included had confirmed recurrence of PE with CT, one within seventeen days, one within fifteen days, one within thirteen days, and one after four days and again after twenty-eight days. Three dogs were euthanized at recurrence, due to a poor prognosis as masses compatible with hemangiosarcomas were observed on echocardiography.

*Clinical signs reported by the owner*
The prevalence for each clinical sign is shown in Figure 4. Dyspnea (86%) was the most common clinical sign reported by the owner. Furthermore, lethargy (71%), anorexia (57%), and exercise intolerance (57%) were reported in most cases. Out of the seven dogs included in this study, five dogs had polydipsia. However, three were excluded from calculation of prevalence because polydipsia was already present since long time, being sometimes related to a known underlying condition such as hyperadrenocorticism, and therefore deemed unrelated to the CT. The prevalence of polydipsia at first visitation, as a sign possibly related to CT, was 29%.
At recurrence, three dogs presented with polydipsia. However, two were excluded from prevalence analysis due to the above-mentioned reasons, one of which was the dog with two recurrence episodes. The prevalence of polydipsia at recurrence was 20%, and the total prevalence combining all visits was therefore 25%.

*Physical examination findings*
The different physical examination findings encountered and their prevalence are shown in Figure 5. A weak pulse (86%), muffled heart sounds (86%), and tachycardia (86%) were the most common abnormalities found during physical examination.

# 7. Discussion

In this research project focusing on dogs with confirmed CT due to PE, we have identified a total prevalence of polydipsia of 37% and 36% in the retrospective and prospective study, respectively. When the dogs included in both studies are considered as a single group, the resulting prevalence is 35%, which is higher than that of 12% previously reported in dogs with PE.[9]
Furthermore, in this study, lethargy was identified as the most commonly reported clinical sign in the retrospective part, and dyspnea in the prospective part. Stafford Johnson and colleagues found a similar prevalence of lethargy in dogs, but a much lower prevalence of dyspnea.[9]
The reason behind these differences in prevalence is unclear. The most likely explanation is the difference in study design, concerning the inclusion criteria. In fact, in this study, dogs with both PE and CT were included, while in the other study, presence of concurrent CT was not necessary. Furthermore, Stafford Johnson and colleagues only included dogs with PE due to infectious causes, suspected idiopathic pericarditis, or cardiac neoplasia, whereas, in our study, we included all dogs with PE and CT, regardless of the underlying cause.

What concerns polydipsia, prevalence in the two parts of this study was only slightly different, but slightly higher in the retrospective one, where every dog for which the owner reported polydipsia was included, as it was not possible to investigate whether this sign was of new appearance. In fact, in the prospective study, some dogs could be excluded after a thorough and conscious interview of the owners, as they reported polydipsia of long duration, and in one case, a comorbidity that could justify this clinical sign (hyperadrenocorticism). Therefore, in the retrospective study, false-positives could have led to the higher prevalence encountered.
Furthermore, as previously mentioned, medication can also lead to polydipsia and therefore to false-positive cases. In 13% of the cases included in the retrospective study, furosemide was administered by the referring veterinarian prior to the visit to the University clinic. This medication could cause polydipsia. However, in this study, polydipsia and furosemide administration were not significantly associated, but an effect of the low number of cases on this analysis is not excluded. It should be noted that furosemide is contraindicated in case of PE with CT, as it can lower the blood pressure even further.[40]

As mentioned above, polydipsia could be the consequence of a variety of diseases. However, considering the relatively high prevalence encountered in this study, inclusion of PE with CT in the differential diagnosis of polydipsia in dogs seems worthwhile. Interesting, prevalence at recurrence was even higher than at first presentation. Therefore, polydipsia could be a useful warning sign of recurrence, detectable by the owner. Early detection of CT could prevent critical deterioration of a patient, and owners could seek life-saving care without delays.
It could be possible that the prevalence at the recurrence was even higher than calculated. In fact, in the retrospective part of the study, twenty dogs appeared to have had an episode of recurrence. However, unfortunately, seven of these dogs had to be excluded from further analyses because of incomplete data.
Of the dogs that experienced recurrence, 62% presented with polydipsia at least once. However, it must be considered that not every dog presented polydipsia at recurrence, even if shown at the time of the first visits. Additionally, this clinical sign could be absent at the time of the first visit but be reported at recurrence. As a result, it seems difficult to predict whether a dog will show polydipsia in case of recurrence. Furthermore, polydipsia could have other causes. Therefore, it would be important to clearly inform owners about the possible significance of the presence or absence of this clinical sign for their pet after discharge.

As explained in the Introduction section, the exact mechanism for which CT would lead to polydipsia remains unknown.
In this report, no relationship between the amount of fluid drained from the pericardial sac and polydipsia was found. However, in only 28 cases the amount of PE drained was noted. Often, the fluid moved to the thoracic cavity after pericardiocentesis and thus no results were available, or pleural effusion was drained as well.
There was also no significant association between the presence of a mass and polydipsia. However, a mass could always be missed on echocardiography.
Polydipsia does not seem to relate to the presence of ascites or other physical examination findings either, and therefore, indirectly, to a more acute or chronic presentation.

Important to note are limitations due to the nature of this study. For what concerns the retrospective study, it is possible that owners did not notice a certain change in behavior or did not report a clinical sign if not specifically asked for its presence or absence. On the other hand, it is possible that the attending veterinarian did not report all the symptoms in the patients' file. This could lead to false-negatives and thus a lower reported prevalence.
Furthermore, polydipsia was considered present when the owner reported a subjective increased water intake observed for their pet, but this was not quantified. The water intake is considered increased when corresponding to 100ml/kg/day or more.[41] However, companion animals often receive water ad libitum or are not the only pets in the house, and most owners do not precisely measure water intake. Furthermore, one study measured water intake in dogs and found that this could vary up to tenfold depending on the level of activity of the individual.[42] As a result, for the purpose of this study, polydipsia should have been better defined as 'perception of increased water intake by the owner'.
Next to the limitation mentioned above, there is a possible bias in case selection. More often there was a less complete anamnesis in dogs that arrived in an unstable condition at the emergency clinic. For this reason, more cases evaluated in the emergency setting were excluded from the study. As a result, relatively more dogs with an acute presentation of PE with CT were excluded, which could have given a distorted view of the prevalence of various clinical signs.

To have a better idea of the true prevalence of polydipsia, a prospective study could be set up, where the owners are asked to objectively measure water intake of their dog regularly. This would take out their subjective interpretation of water intake. Additionally, it would allow determining the baseline water intake for each individual, which makes it easier to determine if a dog is drinking more than usual, even if already known with polydipsia due to comorbidity.
To exclude other causes of polydipsia other than PE with CT, routine blood tests and urinalysis could be added to the study design. To further distinguish if a cardiac tumor is present or not, more advanced diagnostic imaging could be used next to echocardiography.[43]
Another possibility is to look at the hormones named in the Introduction section, related to thirst. As said, increased levels of AVP and Ang II are related to an increase in thirst. However, AVP measurement can only be performed in a small number of specialized laboratories, is very time-consuming and the physiological range is often below the detection limit.[44] An alternative to AVP is copeptin. Copeptin is a precursor of AVP and mirrors AVP levels in blood plasma. Copeptin tests are more sensitive, which means they can detect lower levels, and they are already used in a clinical setting.[44,45] For Ang II, various tests have been used in an experimental setting,[46] and its measurement could also be considered.
The downside of such a study design is its feasibility. Dogs may come into the clinic in critical conditions and require immediate care. The owner should first give informed consent before a blood sample, or a urine sample is taken. And only after the blood sample is taken, treatment can be started. This would be ethically unacceptable if the dog is unstable.

# 8. Conclusion

In conclusion, the total prevalence of polydipsia in dogs with PE and CT encountered in this study is 35 %, higher than previously reported in dogs with PE. No association between polydipsia and specific clinical findings was found, therefore elucidation of the possible underlying mechanism is not possible.

While it seems difficult to predict whether an individual dog will show polydipsia in case of PE with CT, its relative high prevalence makes inclusion of this condition in its differential diagnosis worthwhile. Furthermore, owners of dogs with CT discharged after pericardiocentesis could be advised to monitor their pets for appearance of this clinical sign as a possible indication of recurrence. Further research is recommended, and a multi-centered study performed during a longer period of time would be needed to include more animals. To make the study more objective, owners could be asked to measure water intake, and additional tests could be considered.

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# Appendix 1. Checklist clinical findings

| **Anamnesis** | Present? |
|---|---|
| Polydipsia | |
| Anorexia | |
| Vomiting | |
| Diarrhea | |
| Coughing | |
| Dyspnea | |
| Lethargic | |
| Collapse | |
| Exercise intolerance | |
| Weight loss | |

| **Physical examination** | Present? |
|---|---|
| Dyspnea | |
| Tachypnea | |
| Coughing | |
| Tachycardia | |
| Weak pulse | |
| Low blood pressure | |
| Muffled heart sounds | |
| Pulsus paradoxus | |
| Pale mucous membranes | |
| Prolonged capillary refill time | |
| Cold extremities | |
| Ascites | |
| Distention of the liver | |

| **Echocardiographic findings** | |
|---|---|
| Compression of the right atrium | |
| Diastolic collapse of the right ventricle | |
| Presence of a mass | |

# Appendix 2. Tables and Figures

**Table 1.** Affected breeds

| *Breed* | *Number (%)* |
|---|---|
| *Labrador Retriever* | 10 (17,9%) |
| *Mixed breed* | 7 (12,5%) |
| *Golden Retriever* | 5 (9,0%) |
| *American Bulldog* | 4 (7,1%) |
| *Stabyhoun* | 2 (3,6%) |
| *Vizsla* | 2 (3,6%) |
| *German Shorthaired Pointer* | 2 (3,6%) |
| *French Bulldog* | 2 (3,6%) |
| *Bullmastiff* | 2 (3,6%) |
| *Boerboel* | 1 (1,8%) |
| *English Cocker Spaniel* | 1 (1,8%) |
| *Pit Bull* | 1 (1,8%) |
| *Airedale Terrier* | 1 (1,8%) |
| *Dachshund* | 1 (1,8%) |
| *Beagle* | 1 (1,8%) |
| *Dandie Dinmont Terrier* | 1 (1,8%) |
| *Shar Pei* | 1 (1,8%) |
| *Great Pyrenees* | 1 (1,8%) |
| *Drentsche Patrijshond* | 1 (1,8%) |
| *Dutch Shepherd* | 1 (1,8%) |
| *West Highland Terrier* | 1 (1,8%) |
| *Cane Corso* | 1 (1,8%) |
| *Staffordshire Bullterrier* | 1 (1,8%) |
| *Jack Russel Terrier* | 1 (1,8%) |
| *Bloodhound* | 1 (1,8%) |
| *Rottweiler* | 1 (1,8%) |
| *Boxer* | 1 (1,8%) |
| *Pug* | 1 (1,8%) |
| *German Shepherd* | 1 (1,8%) |

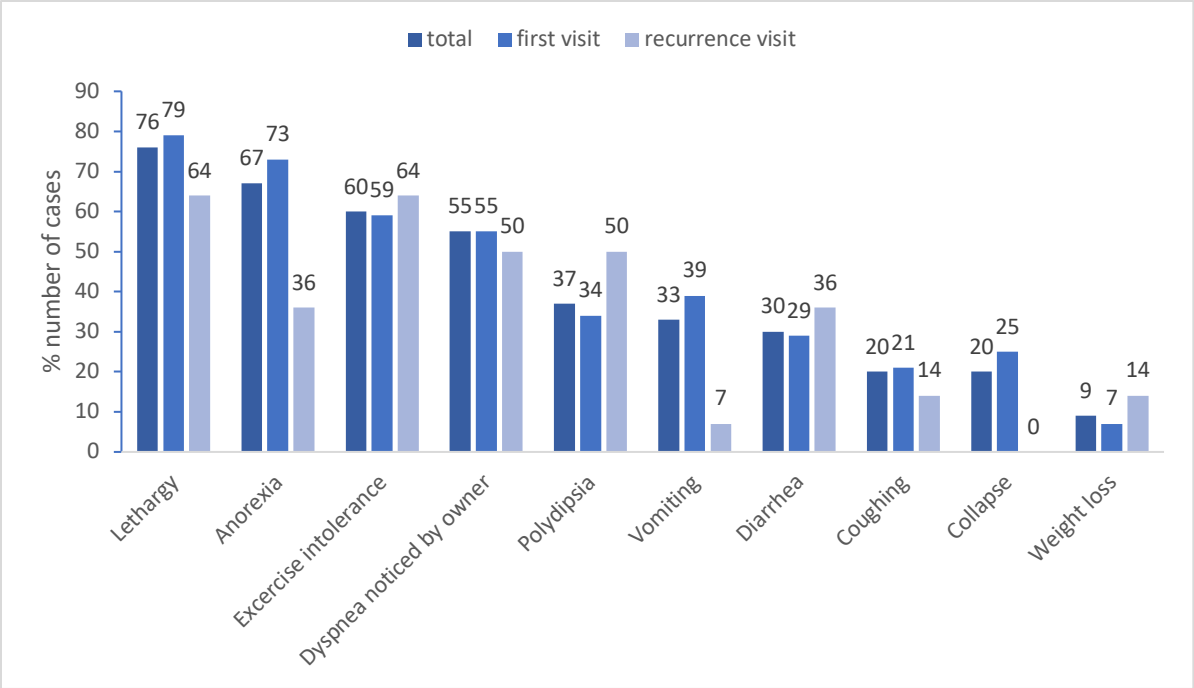


**Figure 2.** Clinical signs reported by the owner (%) in the retrospective study. In total n=70, on the first visit n=56, at recurrence n=14

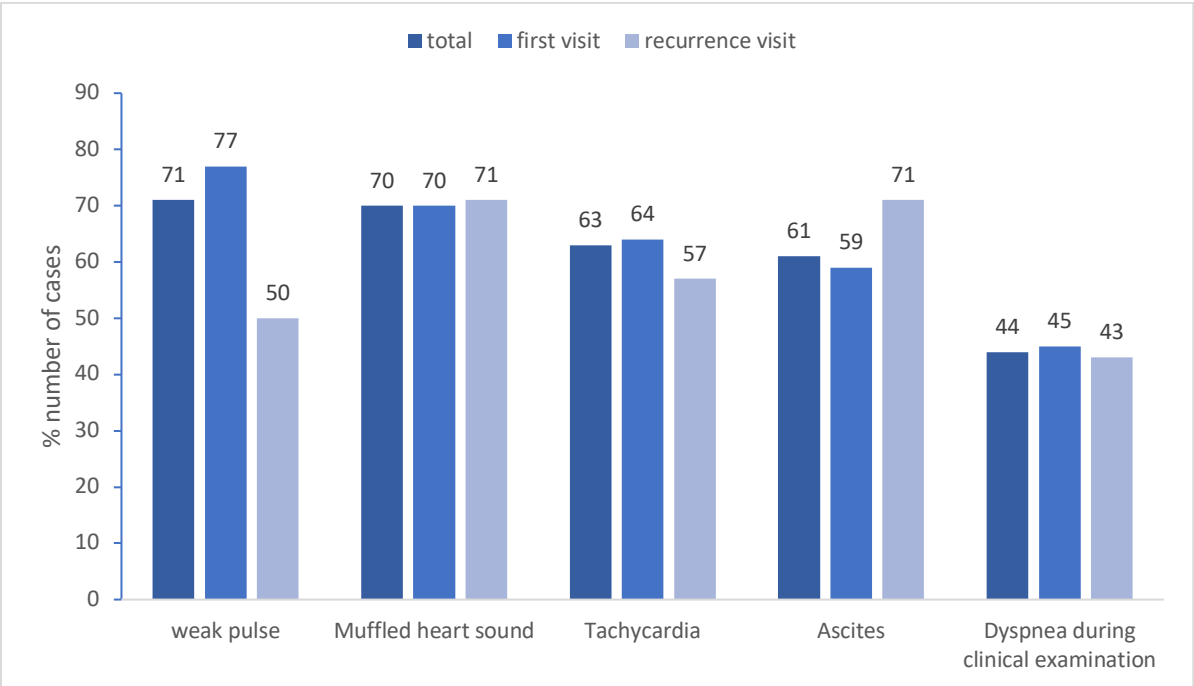


**Figure 3.** Findings during physical examination (%) in the retrospective study. In total n=70, on the first visit n=56, at recurrence n=14

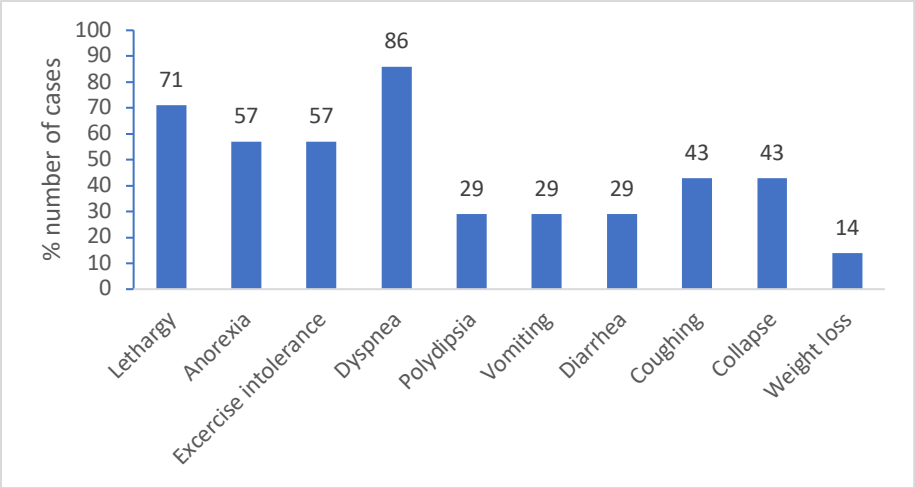


**Figure 4.** Clinical signs reported by the owner (%) of the prospective study (n=7)

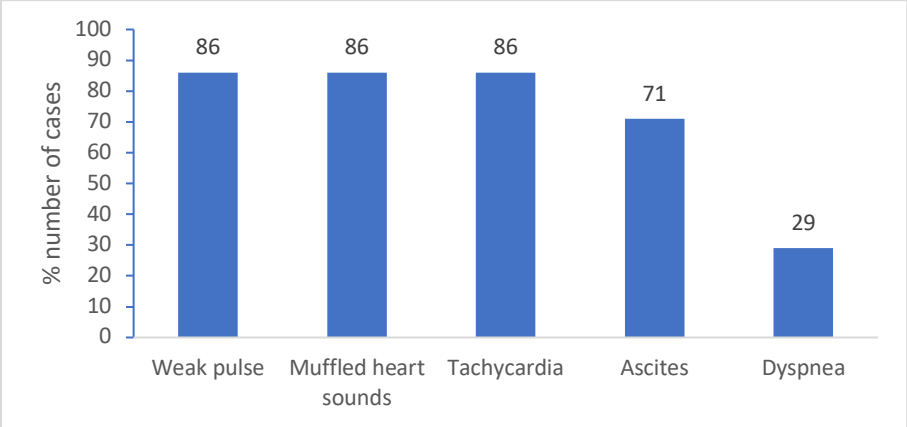


**Figure 5.** Physical examination findings (%) of the prospective study (n=7)