1   **Pyloric localisation in 57 dogs of breeds susceptible to gastric dilatation-**

2   **volvulus in the UK using computed tomography**

3

4   **A.W. Tomlinson[1], S.M. Lillis[2], A.J. German[1,3] and R.D. Burrow[1]**

5

6   [1] School of Veterinary Science, University of Liverpool, Neston, UK.

7   [2] College of Veterinary Medicine, School of Veterinary and Life Sciences, Murdoch University, Perth,

8   Australia.

9   [3]Institute of Ageing and Chronic Disease, University of Liverpool, Liverpool, UK

10

11   Corresponding author address:

12   Andrew Tomlinson

13   University of Liverpool

14   Small Animal Teaching Hospital

15   Leahurst Campus

16   Neston

17   Cheshire

18   CH64 7TE

19

21

22   **Word count:** 3723

23 **Introduction**

24 The anatomic location of the pyloric part of the canine stomach is important for the veterinary surgeon

25 particularly when performing a gastropexy procedure either prophylactically in an at-risk individual

26 (Ward and others 2003, Allen and Paul 2014), following an episode of gastric dilatation/volvulus

27 (GDV) or following splenic torsion (Millis and others 1995, Neath and others 1997). The aim of a

28 gastropexy is to create a permanent adhesion between the pyloric antrum and the right abdominal

29 wall without interfering with the stomach's normal position or function (Rasmussen 2003). Following a

30 ventral midline coeliotomy the normal abdominal topography is altered due to patient positioning,

31 pneumoperitoneum and reduced support from abdominal musculature. Therefore, the anatomically

32 correct position to perform a gastropexy is unclear and often based on intraoperative assessment by

33 the surgeon.

34

35 CT has been used to evaluate anatomical aspects of the canine abdomen in previous studies, but has

36 not yet been used to define the location of the canine pylorus (Rivero and others 2009, Beukers and

37 others 2013, Hoey and others 2013, De Rycke and others 2014, Gregori and others 2014). The aim

38 of this study was to review abdominal CT scans of dogs of breeds susceptible to GDV in the UK

39 (Evans and Adams 2010) and describe the location of the pylorus within the abdominal cavity. A

40 secondary aim of the study was to determine the position of the pylorus relative to previously reported

41 gastropexy locations.   This study represents a preliminary anatomical CT study with a view to

42 performing a subsequent case-control study.

43

44 **Material and Methods**

45 **Study design and ethics**

46 This was a retrospective observational study approved by the University of Liverpool Veterinary

47 Research Ethics Committee (VREC130). All owners gave their written consent for the use clinical

48 records and CT images for the study.

49

50 **Study population and eligibility criteria**

51 Medical records of dogs presenting to the Small Animal Teaching Hospital, University of Liverpool

52 between January 2007 and March 2013 that had abdominal CT examination were reviewed. Dogs

53 were selected for the study if there was (1) no evidence of cranial abdominal disease, (2) no

54 significant haematological or serum biochemical abnormalities, (3) no splenic changes distorting the

55 splenic capsule, (4) no cranial abdominal organomegaly and (5) the CT scan was performed in sternal

56 recumbency.

57

58 **Computed tomography**

59 All patients were anaesthetised or sedated to complete the CT scan. Each patient underwent an

60 abdominal CT scan using a four slice helical CT scanner (Siemens Volume Zoom, Siemens AG,

61 Munich Germany). The contrast agent (Omnipaque 350, GE Healthcare, Buckinghamshire, UK) was

62 administered using a power injector at a dose of 700mg iodine/kg bodyweight to a maximum volume

63 60mLs at a rate of 3mL/s. Data were acquired using the following parameters: 120 kVp, 84-185

64 effective mAs, 2.5 mm slice collimation and 0.5s rotation time. Images were acquired after

65 hyperventilation to induce apnoea. Contiguous images with 3mm slice thickness were reconstructed

66 using a fast body kernel (B30F kernel). Consensus review of CT images was made by an ACVR

67 board-certified radiologist (SL) and an ECVS resident in small animal surgery (AT). All images were

68 assessed and measured using DICOM image reading software (OsiriX v.4.1.1 64-bit; Pixmeo,

69 Switzerland), with images being viewed in a soft tissue window (window width 350, window level 50).

70 The position of the pylorus was defined as the point where the pyloric part of the stomach joined the

71 descending duodenum (Figure 1) in the transverse image slices. The 'point' tool in the image reading

72 software was used to generate a 3D coordinate for the pylorus at the agreed location. The most

73 caudal aspect of the right thirteenth rib (R13) was located in the dorsal plane image slices. The z

74 value (craniocaudal plane) was recorded at this location. The z value of the caudal aspects of the

75 right 9th (R9), 10th (R10) and 11th (R11) ribs were made in the same image slice (Figure 2). The z

76 value 2cm (2CM13) and 3cm (3CM13) caudal to R13 were calculated by adding 2cm and 3cm to the

77 R13 value respectively. To account for variation in body size, linear measurements were divided by

78 ventral abdominal length (defined as the distance between the most caudal aspect of the xiphoid

79 process and the cranial aspect of the pubis as measured on the transverse CT images).

80

81 **Clock-face angle**

82   The clock-face angle was measured in the transverse plane from a line that intersected the centre of

83   the pyloric canal and the centre of the abdominal cavity (CAC), defined as the point half way along a

84   vertical line from the dorsoventral axis of the vertebral body to the linea alba, relative to the sagittal

85   plane (Figure 3). When the pylorus was located to the left of midline, it was given a negative value.

86   The generated data were sorted in 30° increments, according to units on a clock-face: assuming that

87   the patient was in dorsal recumbency with the surgeon was facing cranially, the ventral midline was

88   defined as the 12 o'clock position, and the vertebral body defined as the 6 o'clock position (Figure 4).

89

90   **Position of the pylorus**

91   The position of the pylorus was calculated relative to the position of R9, R10, R11, R13, 2CM13 and

92   3CM13 at the 8, 9 and 10 o'clock positions on the right abdominal wall (RAW) at the predetermined z

93   value locations using the transverse image slices. The 8, 9 and 10 o'clock locations were identified

94   by drawing a line from the CAC that intersected the right body wall at an angle of 120°, 90° and 60°

95   respectively. A 3-dimensional coordinate for each designated location was obtained using the 'point'

96   tool. Distance along the x-axis was calculated by subtracting the x coordinate of the pylorus from the

97   x coordinate of the selected location. Dorsoventral (y axis) and craniocaudal (z axis) distance were

98   calculated in the same manner. A positive value represented left lateral, dorsal or cranial location of

99   pylorus relative to the RAW along the x, y and z-axis, respectively. A negative value represented right

100   lateral, ventral or caudal location of the pylorus relative to the RAW along the x, y and z-axis

101   respectively. All values were corrected for ventral abdominal length. For absolute distance

102   calculations, only absolute values were used to determine the magnitude of the distance of the

103   pylorus from the RAW regardless of relative position. Net distance was calculated taking into account

104   positive and negative values to determine the overall position of the pylorus relative to the RAW.

105   Overall distance (OD) was calculated using the Pythagorean Theorem in two stages:

106
$$a = \sqrt{x^2 + z^2}$$

107   Where a is the calculated distance in the combined mediolateral and craniocaudal plane.

108
$$OD = \sqrt{a^2 + y^2}$$

109

110   **Statistical analysis**

111 All data are expressed as median (range), except where indicated. Statistical analyses were

112 performed on absolute and overall distance with computer software (Stats Direct version 2.6.8, Stats

113 Direct Ltd), with the level of significance set at $P<0.05$ for two-sided analyses. The Shapiro-Wilk test

114 was used to determine whether or not datasets followed a normal distribution, with parametric and

115 non-parametric tests performed as appropriate. Comparisons amongst three or more related

116 variables (e.g. position of the pylorus relative to different external landmarks) were made with the

117 Friedman test, with *post hoc* comparisons made, where appropriate, using the Conover test. Given

118 the multiple comparisons performed, a Bonferroni correction was applied.

119

120 Factors affecting the overall distance of the pylorus relative to the RAW at the 10R 10 o'clock position

121 were assessed using linear regression analysis. Factors tested included signalment (e.g. age, sex,

122 neuter status, breed groups, and breed), body weight, body surface area and body condition score.

123 To assess the effect of breed, dogs were initially assigned to 1 of 3 breed groups (medium, large and

124 giant), and a binary variable created for each group, whereby 1 = from the breed group, and 0 = not

125 from the breed group.   However, given that significant differences were seen, for some

126 measurements, for the medium breed group, additional binary variables were created for 3 medium

127 breeds with largest numbers, namely Boxer, English springer spaniel, and Labrador retriever; dogs

128 were classified according to binary variables, whereby 1 = from the breed, and 0 = not from the breed.

129 Weight status was also classified according to a binary variable, whereby 1 = overweight (based upon

130 a body condition score of 6-9/9), and 0 = not overweight (based upon a body condition score of 4-5/9).

131 Initially, simple linear regression was used. A multiple linear regression model was then constructed,

132 which initially included any variables identified as $P<0.2$ on univariable analysis. Colinearity amongst

133 variables was assessed using variance inflation factors and the reciprocal tolerance (O'Brien 2007),

134 and unnecessary collinear predictors were removed. The model was subsequently refined by

135 backwards-stepwise elimination of the least significant variable at each round, with variables being

136 retained in the final model if they were significant ($P<0.05$).

137

138 **Results**

139 **Characteristics of the study dogs**

140   Fifty-seven dogs met the inclusion criteria, with 37 being male (20 neutered) and 20 being female (14

141   neutered), and their median age was 84 months (range 11 to 151 months). Seventeen different

142   breeds were assessed including Labrador retriever (n=23), Boxer (n=7), English springer spaniel

143   (n=6), Dogue de Bordeaux (n=3), Rhodesian ridgeback (n=3), German shepherd dog (n=3),

144   bullmastiff (n=2) and one each of Japanese Akita, Bassett hound, Bernese mountain dog, bulldog,

145   Dalmatian, Great Dane, Irish setter, Newfoundland, standard poodle and flat coat retriever. Median

146   weight was 34.0 kg (range 16.5-84.3 kg), and median estimated body surface area was $1.1m^2$ (0.7-

147   1.9 m^2). Body condition score was available for 48 of the 57 dogs, and median body condition score

148   was 5/9 (range 4-9/9), with 33 dogs in ideal weight and 15 dogs that were overweight.

149

150   **Clock-face position**

151   The results are summarised in Table 1. In 56 (98%) of patients the pylorus was located in the right

152   hemiabdomen; in forty-nine cases (88%), the pylorus was located in the right ventral quadrant of the

153   abdomen, and was located at the 9-10 o'clock position in 36 (63%) of these cases. In one case, the

154   pylorus was located to the left of midline at the 12-1 o'clock position. The remaining 7 cases were

155   located in the right craniodorsal quadrant.

156

157   **Position of the pylorus relative to predefined locations:**

158   *X-axis distance*

159   The results are summarised in Table 2. For each gastropexy location, the distance between the

160   pylorus and RAW along the x-axis was significantly different at the 8, 9 and 10 o'clock positions.

161   Dorsally (i.e. at the 8 o'clock position), the distance of the pylorus from the RAW along the x-axis was

162   significantly greater at the 9R, 10R and 11R positions compared to the 13R, 2CM13 and 3cm13

163   positions. Conversely, ventrally (i.e. at the 10 o'clock position), the distance between the pylorus and

164   RAW along the x-axis was significantly greater at the 3CM13, 2CM13 and 13R positions than at the

165   11R, 10R and 9R positions. Distance between the pylorus and RAW at the 9 o'clock position was

166   consistent regardless of gastropexy location.

167

168   *Y-axis distance*

169   The results are summarised in Table 3. With the exception of 3cm13R (10 o'clock and 8 o'clock) and

170   2cm13R (10 o'clock and 8 o'clock), the distance between the pylorus and the RAW along y axis was

171   significantly different at the 8, 9 and 10 o'clock position for each gastropexy location. The pylorus was

172   consistently located ventral to the 8 o'clock position on the RAW. Distance between the pylorus and

173   the 8 o'clock position on the RAW was significantly greater the more cranial the gastropexy location.

174   The pylorus was consistently located dorsal to the 10 o'clock position on the RAW. Conversely

175   distance between the pylorus and the RAW at this location was significantly greater the more caudal

176   the gastropexy location. Distance between the pylorus and RAW along the y-axis was significantly

177   lower at the 9 o'clock position at all locations (P≤0.001) with the pylorus consistently located in a slight

178   dorsal position relative to the RAW. Total distance at the 2cm13R 9 o'clock position was less than at

179   all other locations (P < 0.0001), but there were no other differences amongst other locations.

180

181   *Z-axis distance*

182   The results are summarised Table 4. For the 3CM13, 2CM13, R13, and R11 locations, median

183   absolute distance were significantly different from each other and significantly greater than the

184   median absolute displacement at R10 and R9 (P<0.001). The R10 and R9 location result in a median

185   absolute distance of 5.8% and 5.4% of ventral abdominal length respectively which were not

186   significantly different from each other (P=0.1). A net caudal and cranial position of the pylorus relative

187   to the RAW occurred at R9 and R10 respectively.

188

189   ***Overall Distance:*** The overall distance between the pylorus and the RAW is shown in Table 5, and

190   was greatest at the 3CM13 location in the 10 and 9 o'clock positions, being significantly different from

191   all other locations (*P*<0.001). Overall distance was least at the 10R and 9R 10 o'clock position which

192   were not significantly different from each other (P=0.31) but significantly less than all other locations

193   (P<0.001). Finally, there was no difference between 11R 8 o'clock position and the 10R 9 o'clock

194   (P=0.1) and 9R 9 o'clock (P=0.17) positions.

195

196   **Factors affecting overall distance at the 10 o'clock position of the 10th rib**

197   On simple linear regression analysis (Table 6), factors associated with overall distance at 10R 10

198   o'clock were medium-sized (*R*=0.43, *R^2*=0.19, *P*<0.001) and large (*R*=-0.35, *R^2*=0.12, *P*=0.008) breed

199 dogs. No other factor was found to be of significance, although age was also eligible (at $P<0.2$) for

200 inclusion in the preliminary multiple linear regression model ($R=$ -0.18, $R^2=$ 0.03, $P=0.171$).

201 Therefore, a multiple regression model was then built including three factors: medium breed, large

202 breed, and age. After refinement by backwards stepwise elimination, the best-fit model was one that

203 included a single variable, medium-sized breed dogs ($R=0.43$, $R^2=0.19$, $P<0.001$, Table 6). Given

204 this finding, the effect of breed was explored further by repeating linear regression analysis, to include

205 binary variables for the three most common medium-sized breeds (e.g. Labrador retriever, English

206 springer spaniel, and boxer). On simple regression analysis, both Labrador retriever ($R=0.26$,

207 $R^2=0.07$, $P=0.047$) and English springer spaniel ($R=-0.61$, $R^2=0.37$, $P<0.001$) were also significant.

208 Therefore, a second multiple regression model was built, which included five factors: medium breed,

209 large breed, age, Labrador retriever, and English springer spaniel. After refinement by checking

210 collinearity and by backwards stepwise elimination, the best-fit model was one that included a single

211 variable, English springer spaniel ($R=$ -0.61, $R^2=$ 0.37, $P<0.001$, Table 6).

212

213 **Discussion**

214 The objective of the current study was to define the location of the pylorus in canine breeds

215 considered susceptible to GDV in the UK. Using CT, we demonstrated that the pylorus was located in

216 the right hypochondriac/epigastric region typically at the level of the 9th intercostal space. In 88% of

217 cases, the pylorus was located in the right cranioventral abdominal quadrant and in the vast majority

218 of cases (63%) at the 9 – 10 o'clock position. Our results suggest that the most frequently used

219 gastropexy locations are significantly different to the natural anatomic location of the pylorus.

220

221 The overall distance between the pylorus and the RAW is the summation of distance in all three

222 planes. This was calculated using the Pythagorean Theorem in two stages (Table 5). The overall

223 distance between the RAW and R13 and 3CM13 is equivalent to 29 and 36% of ventral abdominal

224 length respectively, significantly greater than the distance between the RAW and 11R (average

225 distance 18 – 20% ventral abdominal length). Least overall distance between the pylorus and RAW

226 occurs at the 9R and 10R 9 – 10 o'clock position, equivalent to 15 – 18% of ventral abdominal length.

227 This is significantly less than the distance seen between the pylorus and RAW at the traditional

228 gastropexy locations and is largely attributed to mediolateral distance rather than a product of the

229 increased distance between the pylorus and RAW in the craniocaudal or dorsoventral plane which is

230 seen at more caudal gastropexy sites.

231

232 By the nature of the gastropexy procedure, displacement of the pylorus/pyloric antrum towards the

233 RAW must occur and will result in a non-anatomical location of the pylorus (Leib and other 1985,

234 Whitney and other 1989). Based on this study mediolateral distance between the pylorus and RAW

235 measured at least 8% and could be as great as 17% of ventral abdominal length. Typically,

236 gastropexy procedures, with the exception of the circumcostal gastropexy, are described between

237 R13 and 3CM13R. Positive contrast gastrography studies have confirmed that a belt-loop gastropexy

238 results in caudal/caudomedial displacement of the pylorus, which based on our study, could represent

239 caudal and mediolateral displacement of up to 31% and 17% of ventral abdominal length respectively

240 (Whitney and other 1989). Positive contrast gastrography studies have also documented

241 displacement of the pylorus following circumcostal gastropexy which, assuming the gastropexy is

242 completed at 11R, could result on average in caudal and mediolateral displacement of 9% and up to

243 9% respectively (Leib and other 1985).

244 In the authors' opinion, the location to perform a gastropexy in the dorsoventral plane and the

245 dorsoventral position used in GDV studies is inconsistently reported. To make the locations relevant

246 to the surgeon, a clock face analogy was chosen to represent the dorsoventral locations. The

247 distance between the pylorus and RAW was least at the 9 o'clock position and was equivalent to

248 approximately 4% of ventral abdominal length which is consistent regardless of gastropexy location

249 suggesting that the true location of the pylorus lies close to the 9 o'clock position in the dorsoventral

250 plane.

251 The short and long term consequences, if any, of excessive gastric displacement are unknown.

252 Recurrent GD was reported in 5 - 10% of incisional (Benitez and other 2013, Przywara and other

253 2014), 3 - 9% of circumcostal (Leib and other 1985, Eggertsdottir and other 2008) and 3 - 7% of

254 ventral midline gastropexy procedures (Meyer-Lindenberg and others 1993, Ullmann and other 2015).

255 Recurrent GD may represent persistence of factors contributing to the initial GDV episode or be a

256 consequence of the gastropexy procedure. Indeed, the authors would speculate that as previously

257 described inappropriate gastropexy location can result in functional pyloric outflow obstructions and

258 contribute to recurrent episodes of GD (Jennings and other 1992). It is also possible that stretch of

259   antral smooth muscle may alter slow wave propagation and subsequent gastric motility which may

260   contribute to recurrent episodes of GD although these theories are speculative and warrant further

261   investigation (Publicover and Sanders 1985).

262

263   One of the main limitations of our study is to base our measurements on the pyloric canal. Whilst the

264   authors accept that the pyloric canal is not the recommended site to perform gastropexy, it is a site

265   which can be consistently and easily identified on CT scans thereby allowing more reliable

266   comparisons between individuals. This does mean that an assumption was made that traction and

267   subsequent displacement of the pyloric antrum would result in proportional displacement of the

268   pylorus. Further studies are required to assess whether a gastropexy performed on the pyloric antrum

269   actually result in significant displacement of the pylorus relative to its normal anatomic position.

270   Other limitations of this study are mainly attributed to its retrospective nature. Breed selection was

271   made based on findings of Evans and Adams (2010). Ideally, more breeds considered at higher risk

272   of GDV (e.g. Great Dane) would have been evaluated but this was limited by case availability. Patient

273   positioning was optimised for the presenting complaint and not this study. As such, some patients

274   may not have been lying completely square on the gantry and contributed to some variation in the

275   measurements obtained. Sternal recumbency was chosen for this study as it was hypothesised to

276   most closely resemble normal abdominal positioning in the ambulatory and sternally recumbent

277   patient. Studies quantifying the effect of recumbency on the position of abdominal organs in

278   veterinary patients are lacking and are often referenced to a static point rather than the natural

279   location of the target organ. Respiratory motion is reported to cause variation in the position of cranial

280   abdominal organs in human and veterinary studies (Oliveira and others 2014). In human and

281   veterinary patients, respiratory motion artefact is reduced when the patients are placed in prone or

282   ventral recumbency respectively (Kim and others 2007, Oliveira and other 2014). While this may not

283   be of immediate significance on any one individual scan, a scan performed in ventral recumbency

284   may help limit the effect of respiratory induced variation across the sampled population. Table-top

285   pressure has been shown to cause variation in the position of caudal abdominal structures in human

286   patients with prostate cancer which is more pronounced in the supine position (Bentel and others

287   2000). Similar studies have not been conducted in the veterinary literature although the authors

288   would speculate that the shape of the thoracic cavity should provide some protection from the effects

289 of table top pressure to cranial abdominal organs although the effects of pressure on caudal

290 abdominal structures and secondary effect on cranial abdominal structures is unknown.   Daily

291 fluctuation in the volume of the colon and bladder are reported to be responsible for variation in

292 caudal abdominal organ position in human and veterinary studies (Bentel and other 2000, Nieset and

293 others 2011). All patients are typically starved for at least twelve hours before the CT examination is

294 completed. Nevertheless, there was varying degrees of gastric distension either with gas and/or food

295 material. No studies in the human or veterinary literature report the effects of gastric distension on

296 pyloric position, although it is possible this could contribute to variation in the measurements made in

297 this study. Linear measurements were standardised to ventral abdominal length to enable comparison

298 across breeds and individuals of varying size. Both standardising to body weight and body surface

299 area was considered; however, this does not take into account the body condition of individuals which

300 may have resulted in over- or under-estimation of measurements in under- and over-conditioned

301 individuals, respectively.

302

303 **Conclusion**

304 This study demonstrates that reconstructed CT images can be used to accurately document the

305 location of the canine pylorus. We found that the pylorus is located within the costal arch in all cases

306 and in the right cranioventral abdomen in the vast majority of cases. Current recommended sites to

307 perform a gastropexy could result in significant displacement of the pylorus relative to its natural

308 anatomical location. With this in mind further additional CT studies are required to document the

309 position of the pylorus in dogs which have previously had a gastropexy following GDV. Case-control

310 studies could then be considered where by outcomes are compared between dogs that had a

311 gastropexy performed at different locations

312

316

317 **References**

318   ALLEN, P. & PAUL, A. (2014). Gastropexy for prevention of gastric dilatation-volvulus in dogs: history

319   and techniques. *Topics in Companion Animal Medicine* **29**: 77-80.

320   BENITEZ, M.E., SCHMIEDT, C.W., RADLINSKY, M.G. & CORNELL, K.K. (2013). Efficacy of

321   incisional gastropexy for prevention of GDV in dogs. *Journal of the American Animal Hospital*

322   *Association* **49**: 185-189.

323   BENTEL, G.C., MUNLEY, M.T., MARKS, L.B. & ANSCHER, M.S. (2000). The effect of pressure from

324   the table top and patient position on pelvic organ location in patients with prostate cancer.

325   *International journal of radiation oncology, biology, physics* **47**: 247-253.

326   BEUKERS, M., GROSSO, F.V. & VOORHOUT, G. (2013). Computed tomographic characteristics of

327   presumed normal canine abdominal lymph nodes. *Veterinary radiology & ultrasound* **54**: 610-617.

328   DE RYCKE, L.M., KROMHOUT, K.J., VAN BREE, H.J., BOSMANS, T. & GIELEN, I.M. (2014).

329   Computed tomography atlas of the normal cranial canine abdominal vasculature enhanced by dual-

330   phase angiography. *Anatomia, histologia, embryologia* **43**: 413-422.

331   EGGERTSDOTTIR, A.V., LANGELAND, M., FUGLEM, B., MOHN, A. & STIGEN, Ø. (2008). Long‐

332   Term Outcome in Dogs After Circumcostal Gastropexy or Gastrocolopexy for Gastric Dilatation With

333   or Without Volvulus. *Veterinary Surgery* **37**: 809-810.

334   EVANS, K.M. & ADAMS, V.J. (2010). Mortality and morbidity due to gastric dilatation-volvulus

335   syndrome in pedigree dogs in the UK. *Journal of small animal practice* **51**: 376-381.

336   GLICKMAN, L.T., GLICKMAN, N.W., SCHELLENBERG, D.B., RAGHAVAN, M. & LEE, T. (2000).

337   Non-dietary risk factors for gastric dilatation-volvulus in large and giant breed dogs. *Journal of the*

338   *American Veterinary Medical Association* **217**: 1492-1499.

339   GREGORI, T., MANTIS, P., BENIGNI, L., PRIESTNALL, S.L. & LAMB, C.R. (2014). Comparison of

340   computed tomographic and pathologic findings in 17 dogs with primary adrenal neoplasia. *Veterinary*

341   *radiology & ultrasound* **56**: 153-159.

342   HALL, J., WILLER, R., SEIM 3RD, H., LEBEL, J. & TWEDT, D. (1992). Gastric emptying of

343   nondigestible radiopaque markers after circumcostal gastropexy in clinically normal dogs and dogs

344   with gastric dilatation-volvulus. *American journal of veterinary research* **53**: 1961-1965.

345   HALL, J., WILLER, R., SOLIE, T. & TWEDT, D. (1997). Effect of circumcostal gastropexy on gastric

346   myoelectric and motor activity in dogs. *Journal of small animal practice* **38**: 200-207.

347 HAMMEL, S.P. & NOVO, R.E. (2006). Recurrence of gastric dilatation-volvulus after incisional

348 gastropexy in a rottweiler. *Journal of the American Animal Hospital Association* **42**: 147-150.

349 HOEY, S., DREES, R. & HETZEL, S. (2013). Evaluation of the gastrointestinal tract in dogs using

350 computed tomography. *Veterinary radiology & ultrasound* **54**: 25-30.

351 JENNINGS, P.B., JR., MATHEY, W.S. & EHLER, W.J. (1992). Intermittent gastric dilatation after

352 gastropexy in a dog. *Journal of the American Veterinary Medical Association* **200**: 1707-1708.

353 KIM, Y.S., PARK, S.H., AHN, S.D., LEE, J.E., CHOI, E.K., LEE, S.W., SHIN, S.S., YOON, S.M. &

354 KIM, J.H. (2007). Differences in abdominal organ movement between supine and prone positions

355 measured using four-dimensional computed tomography. *Radiotherapy and oncology* **85**: 424-428.

356 LEIB, M.S., KONDE, L.J., WINGFIELD, W.E. & TWEDT, D.C. (1985). Circumcostal gastropexy for

357 preventing recurrence of gastric dilatation-volvulus in the dog: an evaluation of 30 cases. *Journal of*

358 *the American Veterinary Medical Association* **187**: 245-248.

359 MEYER-LINDENBERG, A., HARDER, A., FEHR, M., LÜERSSEN, D. & BRUNNBERG, L. (1993).

360 Treatment of gastric dilatation-volvulus and a rapid method for prevention of relapse in dogs: 134

361 cases (1988-1991). *Journal of the American Veterinary Medical Association* **203**: 1303-1307.

362 MILLIS, D.L., NEMZEK, J., RIGGS, C. & WALSHAW, R. (1995). Gastric dilatation-volvulus after

363 splenic torsion in two dogs. *Journal of the American Veterinary Medical Association* **207**: 314-315.

364 NEATH, P.J., BROCKMAN, D.J. & SAUNDERS, H.M. (1997). Retrospective analysis of 19 cases of

365 isolated torsion of the splenic pedicle in dogs. *The Journal of small animal practice* **38**: 387-392.

366 NIESET, J.R., HARMON, J.F. & LARUE, S.M. (2011). Use of cone-beam computed tomography to

367 characterize daily urinary bladder variations during fractionated radiotherapy for canine bladder

368 cancer. *Veterinary radiology & ultrasound* **52**: 580-588.

369 O'BRIEN, R.M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality &*

370 *Quantity* **41**: 673-690.

371 OLIVEIRA, C.R., HENZLER, M.A., JOHNSON, R.A. & DREES, R. (2014). Assessment of respiration-

372 induced displacement of canine abdominal organs in dorsal and ventral recumbency using multislice

373 computed tomography. *Veterinary radiology & ultrasound* **56**: 133 - 143.

374 POPE, E.R. & JONES, B.D. (1999). Clinical evaluation of a modified circumcostal gastropexy in dogs.

375 *Journal of the American Veterinary Medical Association* **215**: 952-955.

376 PRZYWARA, J.F., ABEL, S.B., PEACOCK, J.T. & SHOTT, S. (2014). Occurrence and recurrence of

377 gastric dilatation with or without volvulus after incisional gastropexy. *The Canadian veterinary journal*

378 **55**: 981-984.

379 PUBLICOVER, N.G. & SANDERS, K.M. (1985). Myogenic regulation of propagation in gastric smooth

380 muscle. *American journal of physiology* **248**: G512-520.

381 RAGHAVAN, M., GLICKMAN, N., MCCABE, G., LANTZ, G. & GLICKMAN, L.T. (2004). Diet-related

382 risk factors for gastric dilatation-volvulus in dogs of high-risk breeds. *Journal of the American Animal*

383 *Hospital Association* **40**: 192-203.

384 RASMUSSEN, L. (2003). Stomach. In: Textbook of Small Animal Surgery. D. Slatter, Ed.

385 Philadelphia, Saunders. **1:** 592 - 640.

386 RIVERO, M.A., VAZQUEZ, J.M., GIL, F., RAMIREZ, J.A., VILAR, J.M., DE MIGUEL, A. &

387 ARENCIBIA, A. (2009). CT-soft tissue window of the cranial abdomen in clinically normal dogs: an

388 anatomical description using macroscopic cross-sections with vascular injection. *Anatomia, histologia,*

389 *embryologia* **38**: 18-22.

390 THEYSE, L.F., VAN DE BROM, W.E. & VAN SLUIJS, F.J. (1998). Small size of food particles and

391 age as risk factors for gastric dilatation volvulus in great danes. *The Veterinary Record* **143**: 48-50.

392 ULLMANN, B., SEEHAUS, N., HUNGERBUHLER, S. & MEYER-LINDENBERG, A. (2015). Gastric

393 dilatation volvulus: a retrospective study of 203 dogs with ventral midline gastropexy. *The Journal of*

394 *small animal practice* **57**: 18-22.

395 WARD, M.P., PATRONEK, G.J. & GLICKMAN, L.T. (2003). Benefits of prophylactic gastropexy for

396 dogs at risk of gastric dilatation-volvulus. *Preventive Veterinary Medicine* **60**: 319-329.

397 WHITNEY, W., SCAVELLI, T., MATTHIESEN, D. & BURK, R. (1989). Belt-loop gastropexy: technique

398 and surgical results in 20 dogs. *Journal of the American Animal Hospital Association* **25**: 75 - 83.

399

400

401

402

403 **Table 1**

404

Angle (°)	Clock face position	Number of dogs
-30 - ≤0	12 – 1	1
0 - ≤30	11 - 12	5
30 - ≤60	10 - 11	8
60 - ≤90	9 – 10	36
90 - ≤120	8 – 9	7
120 - ≤150	7 - 8	0
150 - ≤180	6 - 7	0

405

406　**Table 2**

407

		Distance		
		10 o'clock (mm/mm)	**9 o'clock** (mm/mm)	**8 o'clock** (mm/mm)
3cm13R		0.114^X	0.145^{WXY}	0.078
		(0.255)	(0.315)	(0.240)
		[0.114; 0.255]	[0.145; 0.315]	[0.078; 0.117]
2cm13R		0.113^X	0.151^{WX}	0.083
		(0.272)	(0.311)	(0.246)
		[0.113; 0.291]	[0.151; 0.311]	[0.083; 0.271]
13R		0.107^X	0.147^Y	0.092
		(0.279)	(0.317)	(0.262)
		[0.107; 0.296]	[0.147; 0.317]	[0.092; 0.237]
11R		0.091^Y	0.141^{WY}	0.120^Y
		(0.260)	(0.310)	(0.290)
		[0.091; 0.273]	[0.141; 0.310]	[0.120; 0.290]
10R		0.086^Y	0.143^{WYZ}	0.128^Z
		(0.240)	(0.291)	(0.301)
		[0.086; 0.273]	[0.143; 0.291]	[0.128; 0.301]
9R		0.086^Y	0.137^{YZ}	0.124^{YZ}
		(0.239)	(0.296)	(0.288)
		[0.086; 0.274]	[0.137; 0.296]	[0.124; 0.288]

Table 3

	Distance		
	10 o'clock (mm/mm)	**9 o'clock (mm/mm)**	**8 o'clock (mm/mm)**
3cm13R	0.113^{α} (0.209) [0.113; 0.225]	0.036^{X} (0.137) [-0.017; 0.246]	0.119^{α} (0.177) [-0.119; 0.177]
2cm13R	0.115^{α} (0.202) [0.115; 0.225]	0.034 (0.140) [-0.015; 0.238]	0.121^{α} (0.183) [-0.119; 0.405]
13R	0.109 (0.185) [0.109; 0.225]	0.037^{X} (0.147) [-0.017; 0.237]	0.133 (0.197) [-0.133; 0.197]
11R	0.090 (0.189) [0.090; 0.388]	0.040^{X} (0.187) [-0.020; 0.250]	0.165 (0.278) [-0.165; 0.332]
10R	0.085 (0.161) [0.085; 0.175]	0.036^{X} (0.195) [-0,027; 0.248]	0.173 (0.232) [-0.173; 0.232]
9R	0.078 (0.156) [0.078; 0.231]	0.045^{X} (0.198) [-0.045; 0.245]	0.179 (0.230) [-0.179; 0.230]

436 **Table 4**

437

438   **Distance**

439

	Absolute (mm/mm)	**Net** (mm/mm)
3cm13R	0.311	0.311
	(0.320)	(0.320)
2cm13R	0.284	0.284
	(0.317)	(0.317)
13R	0.226	0.226
	(0.310)	(0.310)
11R	0.089	0.089
	(0.243)	(0.334)
10R	0.058^{x}	0.037
	(0.184)	(0.328)
9R	0.054^{x}	-0.027
	(0.200)	(0.310)

440   **Table 5**

441

Overall Distance

	10 o'clock (mm/mm)	9 o'clock (mm/mm)	8 o'clock (mm/mm)
3CM13	0.355$^{\alpha}$ (0.290)	0.363$^{\alpha}$ (0.277)	0.351 (0.230)
2CM13	0.333$^{\alpha}$ (0.286)	0.333$^{\alpha}$ (0.271)	0.330 (0.225)
13R	0.289$^{\alpha}$ (0.272)	0.290$^{\alpha}$ (0.253)	0.288$^{\alpha}$ (0.210)
11R	0.181$^{\alpha}$ (0.225)	0.196$^{\alpha}$ (0.277)	0.238^{x} (0.272)
10R	0.146^{x} (0.216)	0.169^{x} (0.297)	0.231^{x} (0.286)
9R	0.138^{x} (0.236)	0.165^{x} (0.288)	0.235^{x} (0.280)

453

454

455   **Table 6**

Variable	R	R^2	Probability
Simple regression			
Age (per year)	-0.18	0.033	0.171
Sex [a]	0.11	0.01	0.406
Neuter status [b]	-0.16	0.02	0.249
Body weight (per kg)	0.02	0.00	0.884
Weight status [c]	-0.01	0.00	0.946
Body surface area (per m^2)	0.03	0.00	0.838
Breed group [d]			
Medium	0.43	0.19	<0.001
Large	-0.35	0.12	0.008
Giant	-0.04	0.00	0.762
Breed [e]			
Boxer	-0.09	0.00	0.505
English springer spaniel	-0.61	0.37	<0.001
Labrador retriever	-0.26	0.07	0.049
Final multiple regression model			

1

Medium breed dogs	0.43	0.19	<0.001

<u>Final multiple regression model</u>

2

English springer spaniel	-0.61	0.37	<0.001

456

457   [a] Classified as a binary variable: male = 1, female = 0. [b] Classified as a binary variable: neutered = 1,

458   intact = 0. [c] Classified as a binary variable: overweight (BCS 6-9/9) = 1, ideal weight (BCS 4-5/9) = 0. [d]

459   Each group classified as a binary variable, whereby: from that breed group = 1; not from that breed

460   group = 0. [e] Classified as a binary variable: from that breed = 1; not from that breed = 0.

461

Figure legend

Figure 1: Transverse CT image slices. Sequential CT slices moving cranially from a) to c) illustrating identification of the pylorus (P). D = ascending duodenum and PA = pyloric antrum.

Figure 2: Dorsal CT image slice at the level of the most caudal aspect of R13 used to assign the z-axis coordinate for R13, R11, R10 and R9.

Figure 3: Transverse CT image slice used to calculate the clock face angle. The angle was measured from a line that intersected the centre of the pyloric canal (red) and the centre of the abdominal cavity (black circle), defined as the point half way along a vertical line from the dorsoventral axis of the vertebral body to the linea alba (green), relative to the sagittal plane.

Figure 4: Transverse CT image orientated in dorsal recumbency. The position of the pylorus in the dorsoventral plane was described using the clock-face analogy with the patient in dorsal recumbency to make the results surgically applicable.

Table 1: Position of the pylorus assembled into clock face units

Table 2: Median (range) absolute distance between the pylorus and RAW along the x-axis at predefined abdominal landmarks. Absolute values in columns with the same upper case letter are not significantly different at P <0.05. Values in italics represent *[median net distance; range]*

Table 3: Median (range) absolute distance between the pylorus and RAW along the y-axis at predefined abdominal landmarks. Absolute values in rows with the same lower case Greek letter are not significantly different at P<0.05. Absolute values in columns with the same upper case letter are not significantly different at P<0.05. Values in italics represent *[median net distance; range]*.

489   **Table 4:** Median (range) absolute and net distances between the pylorus and RAW along the z-axis

490   at predefined abdominal landmarks. Values in columns with the same upper case letter are not

491   significantly different at P<0.05.

492

493   **Table 5:** Median (range) overall distance between the pylorus and RAW relative at predetermined

494   abdominal locations. Values in columns with same upper case letter are not significantly different.

495   Values in rows with same Greek letter are not significantly different at P<0.05.

496

497   **Table 6.** Simple and multiple linear regression analysis to determine factors affecting overall distance

498   between the pylorus and RAW at the 10 o'clock position of the 10th rib.

499

500