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Citation for published version:
Charlesworth, T, Schwarz, T & Sturgess, C 2016, 'Pectus Excavatum: Computed Tomography and Medium Term Surgical Outcome in a Prospective Cohort of 10 Kittens', *Journal of Feline Medicine and Surgery*, vol. 18, no. 8, pp. 613-619 . https://doi.org/10.1177/1098612X15591234

Digital Object Identifier (DOI):
10.1177/1098612X15591234

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
Journal of Feline Medicine and Surgery

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Download date: 01. May. 2024

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Journal:	*Journal of Feline Medicine and Surgery*
Manuscript ID:	JFMS-15-0075.R1
Manuscript Type:	Original Article
Date Submitted by the Author:	06-May-2015

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Keywords:	feline, pectus excavatum, soft tissue surgery, computed tomography, thoracic

Abstract:	Objectives To report the use of computed tomography (CT) in conjunction with clinical signs to assess severity of pectus excavatum (PE) in kittens and to guide surgical decision making. To report medium term outcome in a prospective cohort of kittens undergoing surgical correction. Methods Prospective study of ten, 10-15 week old kittens diagnosed with moderate/severe pectus excavatum Results CT provides additional information useful for selecting patients for surgical correction and for planning that surgery. Traditional radiographic indices (vertebral, frontosagittal) provide reasonable approximations of the CT determined dimensions but these seem to correlate poorly with the severity of clinical signs. Kittens commonly have lateralised deformities which are associated with less severe clinical symptoms, whilst those with midline deformities are associated with more severe clinical signs. 6/7 kittens with severe PE which had a ventral splint applied for 4 weeks had excellent medium term outcomes. Clinical Significance Restriction of diastolic filling by midline sternal deviation may be an important cause of exercise intolerance in cats with pectus excavatum. CT can be used to assess affected kittens and to plan surgery when indicated.

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Pectus Excavatum: Computed Tomography and Medium Term Surgical Outcome in a Prospective Cohort of 10 Kittens

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Abstract

Objectives

To report the use of computed tomography (CT) in conjunction with clinical signs to assess severity of pectus excavatum (PE) in kittens and to guide surgical decision making. To report medium term outcome in a prospective cohort of kittens undergoing surgical correction.

Methods

Prospective study of ten, 10-15 week old kittens diagnosed with moderate/severe pectus excavatum

Results

CT provides additional information useful for selecting patients for surgical correction and for planning that surgery. Traditional radiographic indices (vertebral, frontosagittal) provide reasonable approximations of the CT determined dimensions but these seem to correlate poorly with the severity of clinical signs. Kittens commonly have lateralised deformities which are associated with less severe clinical symptoms, whilst those with midline deformities are associated with more severe clinical signs. 6/7 kittens with severe PE which had a ventral splint applied for 4 weeks had excellent medium term outcomes.

Clinical Significance

Restriction of diastolic filling by midline sternal deviation may be an important cause of exercise intolerance in cats with pectus excavatum. CT can be used to assess affected kittens and to plan surgery when indicated.

Keywords: Feline, Pectus Excavatum, Computed Tomography, Soft Tissue, Thoracic

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Introduction

Pectus Excavatum (PE) is an uncommon, congenital thoracic wall deformity that has been previously documented in a variety of species including man, dogs and cats.[1-4] PE is characterised by a palpable dorsal deviation of the caudal sternebrae resulting in a loss of thoracic volume and potential respiratory compromise.

In man, PE is the most commonly observed thoracic wall abnormality occurring between 1:400 and 1:1000 live births and is commonly associated with connective tissue disorders such as Marfan and Ehlers Danlos syndromes.[6,7] Although familial tendencies have been demonstrated, it may well be a phenotypic response to a variety of underlying conditions and its aetiology is incompletely understood.[7] The incidence of PE in kittens is unknown although the defect seems to be more commonly seen in Bengal cats than domestic short hair (DSH) cats which is suggestive of there being a familial component to its expression.[8] The presence of PE is also positively correlated with flat-chested kitten syndrome in Burmese cats.[9]

In cats, the severity of the deformity is traditionally graded using the vertebral (VI) and frontosagittal (FSI) indices as measured from orthogonal view thoracic radiographs (table 1).[1] In man, however, computed tomography (CT) is commonly employed to assess both the severity of the deformity and to assist with preoperative surgical planning.[5,10]

The authors had noted an apparent discrepancy between the severity of clinical symptoms and radiographically determined vertebral and frontosagittal indices. This

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study describes the use of CT in assessing severity of PE in cats with the hypotheses that standard radiography accurately approximates CT determined indices but that CT will provide additional information to explain the discrepancy between the radiographic and clinical severity of PE. The authors also provide short and medium term follow up for a cohort of 10 kittens who underwent CT +/- surgical correction.

Materials and Methods:

Kittens seen by the primary author in the period 2012-2014 that were between ten and fifteen weeks of age diagnosed with moderate/severe PE (using published VI/FSI ranges) were eligible for inclusion in this study. Full patient data (age breed, weight, history, results of clinical examination) were recorded and cases were allocated a Clinical Severity Score (CSS) (table 2). Kittens who had not had thoracic radiographs taken by the referring veterinarian were radiographed by the primary author during the initial patient assessments. All radiographs were reviewed and VI/FSI calculated by the primary author.

After a full clinical examination, kittens were premedicated with a standard protocol of 0.01mg/kg acepromazine (ACP, Novartis) and 0.02mg/kg buprenorphine (Vetergesic, Alstoe) and preoxygenated in an oxygen cage before induction with propofol (PropoFlo, Abbott Animal Health). Anaesthesia was maintained with isoflurane (IsoFlo, Abbott Animal Health) and supportive intravenous fluid therapy (Hartmann's solution) was administered at 10ml/kg/hr. CT images were acquired using a 2 slice GE Lightspeed scanner and standard helical thoracic protocol with 2.5mm slice thickness with 1.25mm slice interval with the kittens placed in dorsal recumbency. Post contrast series were

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acquired using 2ml/kg ioversol 64% (Optiray 300, Covidien) given as an intravenous bolus immediately prior to scanning. The kitten's lungs were not hyperinflated prior to scanning and no attempt was made to induce a respiratory pause.

All CT scans were assessed at a later date by a board certified diagnostic imager who was blinded to the clinical history/previous radiographs of each kitten. Images were evaluated using dedicated DICOM viewer software (Osirix, Geneva, Switzerland, version 5.8.5 – 64bit) on a computer workstation (Apple Mac Pro, Apple, USA) with a calibrated LCD flat screen monitor (Apple Cinemax Display, 30 inch, Apple, USA). During the course of image evaluation, multiplanar reconstructions and variable windowing were used according to the preference of the diagnostic imager.

All CT studies were assessed for diagnostic quality and for concurrent musculoskeletal abnormalities. CT determined VI and FSI were recorded for each kitten and compared to the radiographically determined VI/FSI using either recent (within 48 hours of CT) radiographs or CT "scout" images (planning radiographs) if judged to be of sufficient quality. Anticipated low case numbers precluded meaningful statistical analysis so scatter plots were used to illustrate any relationships between the measured radiographic and CT VI and FSI values. Correlation coefficients were calculated with an "r value" >0.5 taken as positively correlated and <0.5 as a negative correlation. Bias was assessed using Bland and Altman plots.

Additional CT analysis including measurement of lung volume and assessment of the nature of the sternal deformity. Lung volume was calculated by drawing an ROI around the surface of each lung and then using the ROI volume calculator tool of the imaging

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software. Results (cm^3/kg) were compared against a control population of adult cats who had undergone thoracic CT for non-respiratory disease. The nature of the dorsal deviation of the caudal sternebrae (midline or lateralised) was also recorded as was the location/number of the deviated sternebrae and their proximity to the visible overlying major cardiovascular structures. The presence/absence of lateralisation of the defect was compared to the CSS.

Two kittens had an additional dynamic CT performed to assess the degree of movement of the sternum during the respiratory cycle. A cine protocol was used to take sequential transverse sections at the estimated point of maximum sternal deformity with images acquired every 0.5 seconds for 20 seconds. The distance between the sternum and vertebral body was measured at the points of greatest inspiration and expiration for the two dynamic CT studies and the percentage change calculated.

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Surgical Methods:

Cases that had a severe (<6) VI and clinical signs attributed to PE (CSS 1-5) were considered surgical candidates. The surgical technique was based on that published elsewhere.[11,12] In brief, the kittens were placed in dorsal recumbency and a ventral sternal cast (Dynacast Prelude, BSN Medical) was made conforming to the anticipated postoperative position of the sternum which was facilitated by applying moderate laterolateral compression to the thorax during the casting process. 3.5M polypropylene (Prolene, Ethicon) circumsternal sutures were then placed as single interrupted sutures starting cranially and progressing caudally. The ends of the sutures were left long and passed through the cast before tying under tension whilst simultaneously applying moderate laterolateral thoracic compression. Cases that had no detectable safe corridor for suture passage underwent a minimal dissection to the caudal sternebrae which were then directly retracted ventrally allowing the circumsternal sutures to be passed. This wound was closed using subcutaneous 1.5M or 2M glycomer 631 (Biosyn, Covidien) before routine cast placement. All casts were covered by chest bandages and postoperative thoracic radiographs were taken.

Kittens who underwent surgery were discharged the next day on 5 day courses of 0.05mg/kg meloxicam sid (Metacam, Boehringer Ingelheim) and 20mg/kg potentiated amoxicillin bid (Synulox Palatable Drops, Zoetis). The casts were maintained for 4 weeks at which point they were removed under anaesthesia using an identical anaesthetic protocol as above. Thoracic radiographs were taken to assess the degree of PE correction and postoperative VI's were calculated by the primary author.

Medium term follow up was obtained by email/telephone contact with the owners/referring veterinarians and the kittens were allocated new clinical severity scores. Pre and postoperative CSS were then compared.

Results

Ten kittens met the inclusion criteria during the study period. Breed distribution was: Bengal (5), Domestic Short Hair (4) and Maine Coon (1). There were four female and six male kittens. Median weight (kg) at time of surgery was 1.17 (range 0.65-2.0). Clinical signs reported included: palpable abnormality (10), tachypnoea (7), exercise intolerance (4), at least one previous episode of antimicrobial responsive dyspnoea (3),

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stunting/poor growth (3), dehydration (3), chronic dyspnoea (2), constipation (2) and PU/PD (1). Allocated CSS were: 1(4 kittens), 2(3 kittens), 4(2 kittens) and 5(1 kitten).

All CT scans were deemed to be of diagnostic quality. Two kittens (G, H) did not have radiographs or CT "scout" images of sufficient quality for VI and FSI to be accurately measured and so these cases were omitted from the analysis. Radiographic and CT measurements/indices are given in tables 3 and 4. CT and radiographically determined indices (VI, FSI) were compared and the results shown in figures 1 and 2. CT consistently gave a lower value for the VI with a mean difference of $^{-}$0.53. FSI calculated from CT images tended to be higher than the value calculated from radiographic measurements

The distance between the dorsal most point of the deviated sternum and the overlying vertebra ("c") was determined at maximum inspiration and expiration for each of 3 respiratory cycles for two kittens for which a cine scan was performed. "c" changed by an average of 3.16% in the first kitten and 0.68% in the second.

Lung volume/kg body weight did not appear to be significantly different from that of the control population (mean PE: 37.1 cm^3/kg, mean control: 45.3 cm^3/kg) although low case numbers precluded statistical analysis. CT review showed that the dorsal sternal deviation was lateralised in 5/10 kittens and this was dextral in 4/5 cases. The kitten with sinistral deviation was diagnosed with complete situs inversus. No other musculoskeletal deformities were detected. Kittens which had a lateralised sternal deformity tended to have a lower CSS than those that did not (1,1,1,1,2, versus 2,2,4,4,5).

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The sternebrae closest to the overlying major cardiovascular structures were 5-7 (4 kittens), 5-8 (2 kittens), 6-8 (2 kittens), 6-7 (2 kittens), 4-6 (1 kittens) (see figure 3). The dorsal aspect of the sternal deformity was judged to be in contact with a major cardiovascular structure in 9/10 cases. The tenth case was judged to have a safe corridor for needle passage of 2mm.

Short term/medium term follow up:

Cases A, B, C, F, G, H and I underwent surgery. Case D was PU/PD, anorexic and significantly dehydrated at the time of presentation and was euthanased at the owners request. A post-mortem CT examination was performed in this case with the owner's consent. Cases E and J were judged to have PE of medium severity based on VI. Case E had a CSS of 1 and surgery was not recommended. Case J presented with a CSS of 4 and surgery was recommended but was declined by the owner.

There were no intraoperative complications in any of the cases that underwent surgery. Case A developed furosemide responsive dyspnoea 1 week following surgery that required hospitalisation and oxygen supplementation. Dyspnoea partially resolved but required continued medication. Case A developed cardiorespiratory arrest under anaesthesia for cast removal and did not respond to resuscitation attempts. VI was improved (higher) in all cases that underwent surgical correction (table 5).

No moist dermatitis or pyoderma secondary to cast placement occurred in any of the cases. Owners do not report any clinical symptoms of PE in all surviving kittens.

Follow up data and CSS are listed in table 5.

Discussion:

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Ten kittens were recruited into this study, five of which were Bengals. Although adequate population data is not available for statistical analysis, this tends to support Bengal kittens being at increased risk of PE[8] although bias in the referred population is possible.

The clinical signs reported by the owners and/or breeders were variable. Although some interobserver variation is probable, all clinical histories were taken by the same veterinary surgeon and the severity of historical signs reported seemed to correlate with clinical signs at presentation. Tachypnoea was the most common clinical sign reported after "palpable deformity" which is a diagnostic feature of PE. Tachypnoea was presumed to be due to decreased lung volume and impaired alveolar exchange and forms part of a continuum of signs progressing to exercise intolerance and respiratory distress presumably with increased severity of deformity. This spectrum of signs formed the basis for the CSS which was used in this study. Surprisingly, however, the lung volume (as a proportion of body weight) of affected kittens was not significantly different from a control population of unaffected cats. Larger case numbers and ideally an age-matched control population would allow statistical analysis and verification of these preliminary findings. Results could be further confounded by a compensatory increased depth of respiration seen in affected kittens. More information could be obtained by lung plethysmography but this is not widely available for veterinary patients particularly those with small tidal volumes.

Three of the ten kittens had at least one previous episode of antimicrobial –responsive dyspnoea. In each case, dyspnoea responded rapidly to the administration of

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potentiated amoxicillin. The exact site and cause of the presumed infection is not known but this could be caused by ventilation impairment, failure to clear alveolar secretions or other functional abnormalities.

Although only assessed in two of the 10 cases, the sternum did not move significantly during the respiratory cycle with "c" values varying by only 3.16% and 0.68%. This suggests that radiographically determined VI should be relatively constant independent of the respiratory phase at which they were taken.

There was reasonable correlation between radiographically determined and CT-determined VI and FSI, CT consistently gave a lower value for the VI with a mean difference of 0.53 and FSI calculated from CT images tended to be higher than the value calculated from radiographic measurements. The mean difference in FSI was 0.83 but there was a significant association between the variation and the value of the FSI. These findings suggest that separate reference intervals for normality and severity of VI and FSI are appropriate depending on the imaging modality used but that an appropriate reference interval for CT-calculated FSI can be inferred from the published radiographic FSI values.

No significant concurrent musculoskeletal deformities were identified in any of the affected kittens. In each case the sternum started to deform in the caudal half and the deformity was dorsal but also lateral in 5/10 cases with 4/5 being deviated to the right hemithorax. The case with sinistral deviation of the xiphoid was the cat with situs inversus. The cause of this lateralisation away from the heart is uncertain but possible

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explanations would include displacement of the caudally deviated sternebrae by the heart and/or traction from the diaphragmatic crura during development.

Cardiac perforation is a recognised complication of placing a ventral corrective splint.[12] The deformed sternum was judged to be in contact with either the heart or the caudal vena cava in 9/10 cases with the 10th case having a safe corridor for suture placement of only 2mm. Having demonstrated how close the dorsal sternebrae were to the heart in all our surgical cases, we modified our surgical technique accordingly. No intraoperative complications were encountered and no postoperative complications relating to this approach were seen.

VI and FSI are useful for initial screening of cases into an anatomic severity category - mild, moderate or severe but they do not appear to be useful for determining whether cases with moderate to severe anatomic defects are likely to have severe clinical signs. This would imply that there may be other factors beyond simple musculoskeletal deformity which are contributing to the severity of the clinical signs observed. Cats with lateral deviation of the xiphoid seemed to be associated with a lower clinical score than those kittens with a midline deviation. It has been suggested that clinical symptoms of PE in people may be partially due to a direct compressive or restrictive effects of the displaced sternebrae on the heart itself.[13] Athletic performance is compromised by the inability of the heart to increase diastolic volume to meet increased oxygen demands and direct compression of the right side of the heart is considered to be an indication for surgery in people.[5,13] It is possible that clinical signs seemed to be more severe in cats with a midline pectus deformity due to a similar mechanism whereas the kittens with a lateralised defect had more space available for the heart to increase diastolic

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volume as required. Cardiovascular compromise may therefore be a more significant driver of clinical signs associated with PE in kittens than altered pulmonary function. This could be why case J, that had a midline sternal deviation, had severe clinical signs despite a “moderate” VI (7) and it may be that a different threshold (higher VI) should be used when deciding if kittens with midline defects should undergo surgery.

One case (A) developed significant postoperative furosemide-responsive dyspnoea and then died at the time of cast removal. The apparent initial response to diuretics is suggestive of pulmonary oedema that could be caused either by pulmonary re-expansion, concurrent cardiovascular disease or pulmonary hypertension.[14] Although no significant concurrent cardiovascular disease was detected on the initial CT scan, this modality is not as sensitive as echocardiography when assessing cardiac function. The cause of death at the time of cast removal remains unknown as no post-mortem analysis was permitted.

All cases that survived showed full resolution of clinical symptoms with no exercise intolerance or episodes of dyspnoea reported at the time of follow up. Whilst we used a combination of VI and CSS to determine which cases should benefit from surgery, there was no control population for which treatment was intentionally withheld in order to demonstrate a difference in postoperative outcome as this would have been unethical. We suspect that many cases of severe PE are euthanased due to perceived poor prognosis and financial concerns about treatment costs. This, and the rarity of the condition resulted in only low numbers of cases being recruited despite internet based advertising for case enrolment. We are therefore limited to making broad recommendations about patient selection and treatment efficiency. In our study,

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patients were selected for surgery based on VI and clinical signs. All cases had a sternal cast maintained for 4 weeks and all cases that survived are currently asymptomatic at a mean follow up of 15 months. One of the risks of uncorrected PE is the development of pulmonary hypertension and right side heart failure which the authors have observed in multiple cases < 12mths old. It is possible that some of our cases could develop respiratory symptoms at a later stage and we intend to publish longer term follow up (5 year) data when available.

In summary, conventional radiography yields reasonable approximations of CT-determined VI and FSI. CT was useful in determining the presence/absence of safe corridors for circumsternal suture placement leading to a minor modification of the surgical approach employed for ventral cast placement. CT also allowed detection of cats with midline sternal deviation which may be at risk of developing more severe clinical signs due to diastolic restriction despite relatively mild skeletal deformity. Ten to 15 week old kittens with severe deformity as judged by VI and with compatible clinical signs can be treated by placement of a sternal splint for a 4 week period which can be associated with an excellent medium term outcome.

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Funding Statement

This research received no grant from any funding agency in the public, commercial or not-for-profit sector

Conflict of Interest

The authors declare that there is no conflict of interest.

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Table 1:
Vertebral (VI) and Frontosagittal (FIS) Indices for Assessment of Pectus Excavatum (P.E.)

	FSI	VI
Normal	0.7-1.3 (1.00)	12.6-18.8 (15.0)
Mild P.E.	2.0	>9.0
Moderate P.E.	2.0-3.0	6.0-9.0
Severe P.E.	>3.0	<6.0

Definitions:

FSI: Ratio of the thoracic width at T10 as measured on a dorsoventral radiograph and the distance from the centre of the ventral surface of T10 or vertebra overlying the deformity and the nearest point on the sternum

VI: Ratio of the distance from the centre of the dorsal surface of the vertebral body overlying the deformity to the near point of the sternum and the dorsoventral diameter of the centrum of the same vertebra

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Table 2: Clinical Severity Score

No clinical symptoms recorded	0
Elevated respiratory rate (>30 breaths/min)	1
Elevated respiratory rate, exercise intolerance noted	2
Elevated respiratory rate, intermittent (<50% time) dyspnoea	3
Prolonged periods (>50%) of dyspnoea	4
Prolonged periods of dyspnoea with evidence of significant extra-thoracic disease	5

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Patient ID	Weight (kg)	VI	FSI	Resting Resp (breaths/min)	Age (weeks)	Clinical score
A	0.85	4	4.5	40	15	2
B	0.9	2.2	9.7	40	12	2
C	2	4.3	4.8	40	13	4
D	0.65	4	4.3	60	10	5
E	1.23	6.3	3.3	40	12	1
F	1.62	5.4	2.4	40	13	1
G	1.4	N/A	N/A	30	13	1
H	1	N/A	N/A	48	12	2
I	1.3	5.8	3.3	36	12	1
J	1.1	7	2.5	30	12	4

Table 3: Clinical data and Radiographically Determined Indices at Presentation

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Patient ID	VI	FSI	Lung volume cm^3/Kg	Clinical score
A	3.7	5.1	45.71	2
B	1.6	19.8	62.96	2
C	2.9	5.5	43.16	4
D	3.3	5.6	26.02	5
E	3.4	3.9	28.40	1
F	4.8	2.6	26.87	1
G	4.3	4	27.95	1
H	3.1	5.9	30.35	2
I	4.6	3.2	33.72	1
J	6.2	2.5	46.01	4

Table 4: Calculated indices from CT measurements

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Case ID	Surgery?	Initial VI	Postop VI	Defect Lateralised?	Initial CSS	Folow up CSS	FUP (mths)
A	Y - died	4	N/A	N	2	N/A	N/A
B	Y	2.2	6.3	N	2	0	18
C	Y	4.3	8.3	N	4	0	10
D	N - Euth	4	N/A	N	5	N/A	N/A
E	N	6.3	N/A	Y-R	1	0	24
F	Y	5.4	6.4	Y-R	1	0	24
G	Y	4.3	7.7	Y-R	1	0	18
H	Y	3.2	5.5	Y-R	2	0	18
I	Y	5.8	7.9	Y-L	1	0	4
J	N	7	N/A	N	4	0	4

Table 5: Follow up data. Euth = euthanased; VI = vertebral index; N = No; Y-R = Yes to right; Y-L = Yes to left; CSS = clinical severity score; FUP (mths) = Follow up period (months). N/A = not applicable

NB CT data used for initial VI for cases G, H as radiographic data not available.

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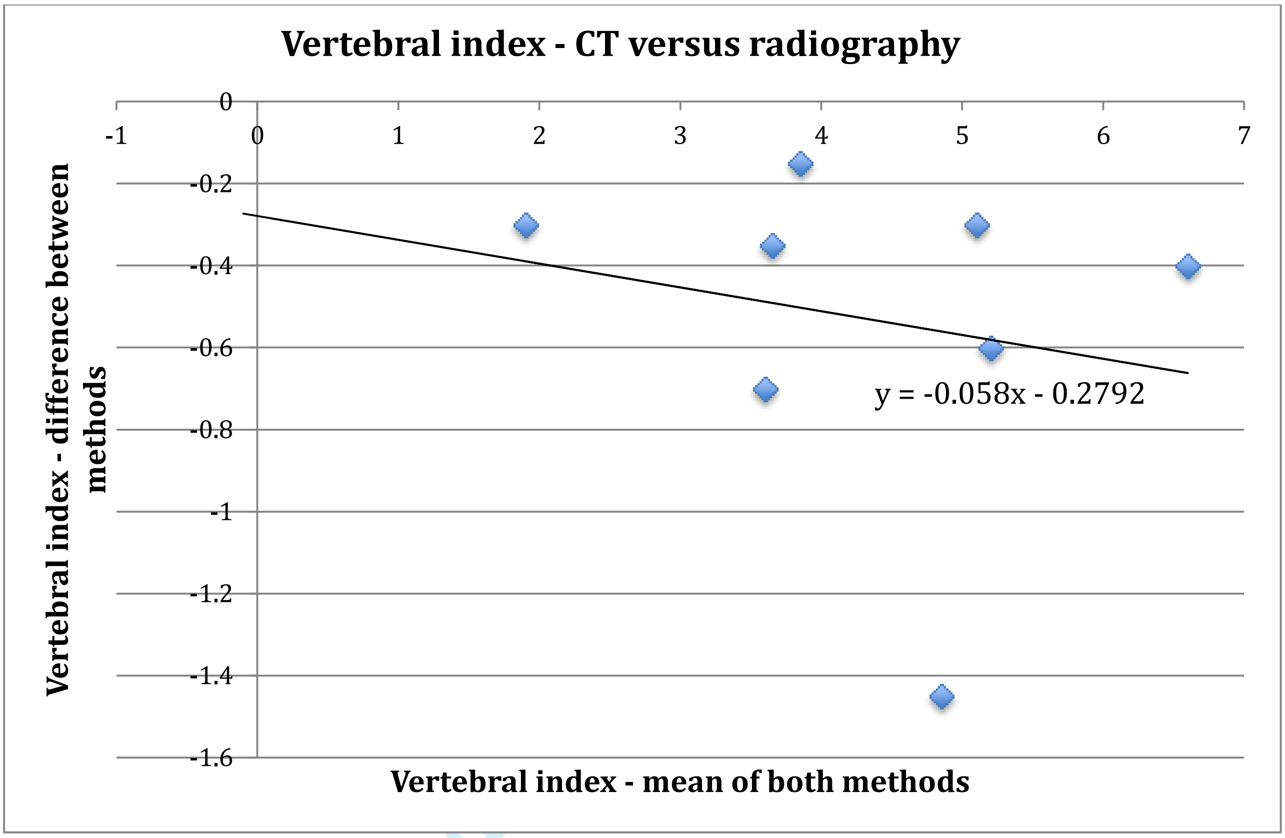

Figure 1 – Bland and Altman plot of the data obtained from 8 paired measurements of the vertebral index using the computed tomography or radiographic image. Correlation R = 0.20 (P = 0.64); slope = -0.058 (P = 0.64); intercept = -0.28 (P = 0.62)

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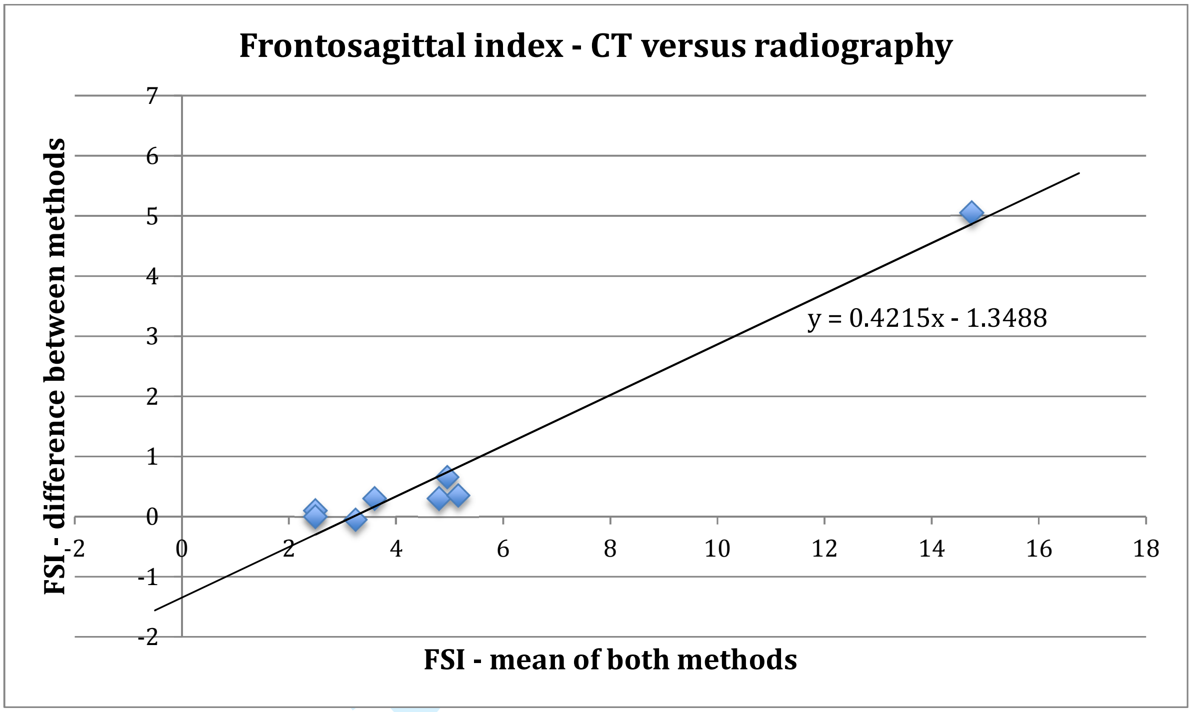

Figure 2 – Bland and Altman plot of the data obtained from 8 paired measurements of the frontosagittal index using the computed tomography or radiographic image. Correlation R = 0.983 (P = <0.01); slope = -0.422 (P = <0.01); intercept = -1.35 (P = <0.01)

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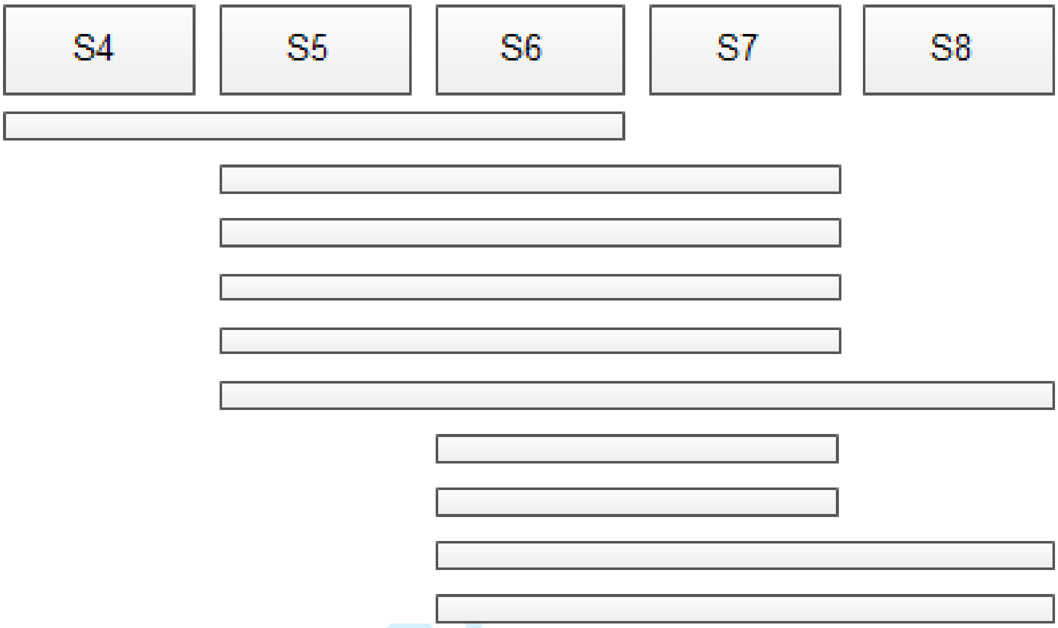
Figure 3– Sternebrae closest to overlying cardiovascular structures in each of the ten kittens



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Abstract

Objectives

To report the use of computed tomography (CT) in conjunction with clinical signs to assess severity of pectus excavatum (PE) in kittens and to guide surgical decision making. To report medium term outcome in a prospective cohort of kittens undergoing surgical correction.

Methods

Prospective study of ten, 10-15 week old kittens diagnosed with moderate/severe pectus excavatum

Results

CT provides additional information useful for selecting patients for surgical correction and for planning that surgery. Traditional radiographic indices (vertebral, frontosagittal) provide reasonable approximations of the CT determined dimensions but these seem to correlate poorly with the severity of clinical signs. Kittens commonly have lateralised deformities which are associated with less severe clinical symptoms, whilst those with midline deformities are associated with more severe clinical signs. 6/7 kittens with severe PE which had a ventral splint applied for 4 weeks had excellent medium term outcomes.

Clinical Significance

Restriction of diastolic filling by midline sternal deviation may be an important cause of exercise intolerance in cats with pectus excavatum. CT can be used to assess affected kittens and to plan surgery when indicated.

Keywords: Feline, Pectus Excavatum, Computed Tomography, Soft Tissue, Thoracic

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Introduction

Pectus Excavatum (PE) is an uncommon, congenital thoracic wall deformity that has been previously documented in a variety of species including man, dogs and cats.[1-4] PE is characterised by a palpable dorsal deviation of the caudal sternebrae resulting in a loss of thoracic volume and potential respiratory compromise.

In man, PE is the most commonly observed thoracic wall abnormality occurring between 1:400 and 1:1000 live births and is commonly associated with connective tissue disorders such as Marfan and Ehlers Danlos syndromes.[6,7] Although familial tendencies have been demonstrated, it may well be a phenotypic response to a variety of underlying conditions and its aetiology is incompletely understood.[7] The incidence of PE in kittens is unknown although the defect seems to be more commonly seen in Bengal cats than domestic short hair (DSH) cats which is suggestive of there being a familial component to its expression.[8] The presence of PE is also positively correlated with flat-chested kitten syndrome in Burmese cats.[9]

In cats, the severity of the deformity is traditionally graded using the vertebral (VI) and frontosagittal (FSI) indices as measured from orthogonal view thoracic radiographs (table 1).[1] In man, however, computed tomography (CT) is commonly employed to assess both the severity of the deformity and to assist with preoperative surgical planning.[5,10]

The authors had noted an apparent discrepancy between the severity of clinical symptoms and radiographically determined vertebral and frontosagittal indices. This study describes the use of CT in assessing severity of PE in cats with the hypotheses that standard radiography accurately approximates CT determined indices but that CT will provide additional information to explain the discrepancy between the radiographic and clinical severity of PE. The authors also provide short and medium term follow up for a cohort of 10 kittens who underwent CT +/- surgical correction.

Materials and Methods:

Kittens seen by the primary author in the period 2012-2014 that were between ten and fifteen weeks of age diagnosed with moderate/severe PE (using published VI/FSI ranges) were eligible for inclusion in this study. Full patient data (age breed, weight, history, results of clinical examination) were recorded and cases were allocated a Clinical Severity Score (CSS) (table 2). Kittens who had not had thoracic radiographs taken by the referring veterinarian were radiographed by the primary author during the initial patient assessments. All radiographs were reviewed and VI/FSI calculated by the primary author.

After a full clinical examination, kittens were premedicated with a standard protocol of 0.01mg/kg acepromazine (ACP, Novartis) and 0.02mg/kg buprenorphine (Vetergesic, Alstoe) and preoxygenated in an oxygen cage before induction with propofol (PropoFlo, Abbott Animal Health). Anaesthesia was maintained with isoflurane (IsoFlo, Abbott Animal Health) and supportive intravenous fluid therapy (Hartmann's solution) was administered at 10ml/kg/hr. CT images were acquired using a 2 slice GE Lightspeed scanner and standard helical thoracic protocol with 2.5mm slice thickness with 1.25mm slice interval with the kittens placed in dorsal recumbency. Post contrast series were

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acquired using 2ml/kg ioversol 64% (Optiray 300, Covidien) given as an intravenous bolus immediately prior to scanning. The kitten's lungs were not hyperinflated prior to scanning and no attempt was made to induce a respiratory pause.

All CT scans were assessed at a later date by a board certified diagnostic imager who was blinded to the clinical history/previous radiographs of each kitten. Images were evaluated using dedicated DICOM viewer software (Osirix, Geneva, Switzerland, version 5.8.5 – 64bit) on a computer workstation (Apple Mac Pro, Apple, USA) with a calibrated LCD flat screen monitor (Apple Cinemax Display, 30 inch, Apple, USA). During the course of image evaluation, multiplanar reconstructions and variable windowing were used according to the preference of the diagnostic imager.

All CT studies were assessed for diagnostic quality and for concurrent musculoskeletal abnormalities. CT determined VI and FSI were recorded for each kitten and compared to the radiographically determined VI/FSI using either recent (within 48 hours of CT) radiographs or CT "scout" images (planning radiographs) if judged to be of sufficient quality. Anticipated low case numbers precluded meaningful statistical analysis so scatter plots were used to illustrate any relationships between the measured radiographic and CT VI and FSI values. Correlation coefficients were calculated with an "r value" >0.5 taken as positively correlated and <0.5 as a negative correlation. Bias was assessed using Bland and Altman plots.

Additional CT analysis including measurement of lung volume and assessment of the nature of the sternal deformity. Lung volume was calculated by drawing an ROI around the surface of each lung and then using the ROI volume calculator tool of the imaging

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software. Results (cm^3/kg) were compared against a control population of adult cats who had undergone thoracic CT for non-respiratory disease. The nature of the dorsal deviation of the caudal sternebrae (midline or lateralised) was also recorded as was the location/number of the deviated sternebrae and their proximity to the visible overlying major cardiovascular structures. The presence/absence of lateralisation of the defect was compared to the CSS.

Two kittens had an additional dynamic CT performed to assess the degree of movement of the sternum during the respiratory cycle. A cine protocol was used to take sequential transverse sections at the estimated point of maximum sternal deformity with images acquired every 0.5 seconds for 20 seconds. The distance between the sternum and vertebral body was measured at the points of greatest inspiration and expiration for the two dynamic CT studies and the percentage change calculated.

Surgical Methods:

Cases that had a severe (<6) VI and clinical signs attributed to PE (CSS 1-5) were considered surgical candidates. The surgical technique was based on that published elsewhere.[11,12] In brief, the kittens were placed in dorsal recumbency and a ventral sternal cast (Dynacast Prelude, BSN Medical) was made conforming to the anticipated postoperative position of the sternum which was facilitated by applying moderate laterolateral compression to the thorax during the casting process. 3.5M polypropylene (Prolene, Ethicon) circumsternal sutures were then placed as single interrupted sutures starting cranially and progressing caudally. The ends of the sutures were left long and passed through the cast before tying under tension whilst simultaneously applying

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moderate laterolateral thoracic compression. Cases that had no detectable safe corridor for suture passage underwent a minimal dissection to the caudal sternebrae which were then directly retracted ventrally allowing the circumsternal sutures to be passed. This wound was closed using subcutaneous 1.5M or 2M glycomer 631 (Biosyn, Covidien) before routine cast placement. All casts were covered by chest bandages and postoperative thoracic radiographs were taken.

Kittens who underwent surgery were discharged the next day on 5 day courses of 0.05mg/kg meloxicam sid (Metacam, Boehringer Ingelheim) and 20mg/kg potentiated amoxicillin bid (Synulox Palatable Drops, Zoetis). The casts were maintained for 4 weeks at which point they were removed under anaesthesia using an identical anaesthetic protocol as above. Thoracic radiographs were taken to assess the degree of PE correction and postoperative VI's were calculated by the primary author.

Medium term follow up was obtained by email/telephone contact with the owners/referring veterinarians and the kittens were allocated new clinical severity scores. Pre and postoperative CSS were then compared.

Results

Ten kittens met the inclusion criteria during the study period. Breed distribution was: Bengal (5), Domestic Short Hair (4) and Maine Coon (1). There were four female and six male kittens. Median weight (kg) at time of surgery was 1.17 (range 0.65-2.0). Clinical signs reported included: palpable abnormality (10), tachypnoea (7), exercise intolerance (4), at least one previous episode of antimicrobial responsive dyspnoea (3),

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stunting/poor growth (3), dehydration (3), chronic dyspnoea (2), constipation (2) and PU/PD (1). Allocated CSS were: 1(4 kittens), 2(3 kittens), 4(2 kittens) and 5(1 kitten).

All CT scans were deemed to be of diagnostic quality. Two kittens (G, H) did not have radiographs or CT "scout" images of sufficient quality for VI and FSI to be accurately measured and so these cases were omitted from the analysis. Radiographic and CT measurements/indices are given in tables 3 and 4. CT and radiographically determined indices (VI, FSI) were compared and the results shown in figures 1 and 2. CT consistently gave a lower value for the VI with a mean difference of $^{-}0.53$. FSI calculated from CT images tended to be higher than the value calculated from radiographic measurements

The distance between the dorsal most point of the deviated sternum and the overlying vertebra ("c") was determined at maximum inspiration and expiration for each of 3 respiratory cycles for two kittens for which a cine scan was performed. "c" changed by an average of 3.16% in the first kitten and 0.68% in the second.

Lung volume/kg body weight did not appear to be significantly different from that of the control population (mean PE: 37.1 cm^3/kg, mean control: 45.3 cm^3/kg) although low case numbers precluded statistical analysis. CT review showed that the dorsal sternal deviation was lateralised in 5/10 kittens and this was dextral in 4/5 cases. The kitten with sinistral deviation was diagnosed with complete situs inversus. No other musculoskeletal deformities were detected. Kittens which had a lateralised sternal deformity tended to have a lower CSS than those that did not (1,1,1,1,2, versus 2,2,4,4,5).

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The sternebrae closest to the overlying major cardiovascular structures were 5-7 (4 kittens), 5-8 (2 kittens), 6-8 (2 kittens), 6-7 (2 kittens), 4-6 (1 kittens) (see figure 3). The dorsal aspect of the sternal deformity was judged to be in contact with a major cardiovascular structure in 9/10 cases. The tenth case was judged to have a safe corridor for needle passage of 2mm.

Short term/medium term follow up:

Cases A, B, C, F, G, H and I underwent surgery. Case D was PU/PD, anorexic and significantly dehydrated at the time of presentation and was euthanased at the owners request. A post-mortem CT examination was performed in this case with the owner's consent. Cases E and J were judged to have PE of medium severity based on VI. Case E had a CSS of 1 and surgery was not recommended. Case J presented with a CSS of 4 and surgery was recommended but was declined by the owner.

There were no intraoperative complications in any of the cases that underwent surgery.

Case A developed furosemide responsive dyspnoea 1 week following surgery that required hospitalisation and oxygen supplementation. Dyspnoea partially resolved but required continued medication. Case A developed cardiorespiratory arrest under anaesthesia for cast removal and did not respond to resuscitation attempts. VI was improved (higher) in all cases that underwent surgical correction (table 5).

No moist dermatitis or pyoderma secondary to cast placement occurred in any of the cases. Owners do not report any clinical symptoms of PE in all surviving kittens.

Follow up data and CSS are listed in table 5.

Discussion:

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Ten kittens were recruited into this study, five of which were Bengals. Although adequate population data is not available for statistical analysis, this tends to support Bengal kittens being at increased risk of PE[8] although bias in the referred population is possible.

The clinical signs reported by the owners and/or breeders were variable. Although some interobserver variation is probable, all clinical histories were taken by the same veterinary surgeon and the severity of historical signs reported seemed to correlate with clinical signs at presentation. Tachypnoea was the most common clinical sign reported after "palpable deformity" which is a diagnostic feature of PE. Tachypnoea was presumed to be due to decreased lung volume and impaired alveolar exchange and forms part of a continuum of signs progressing to exercise intolerance and respiratory distress presumably with increased severity of deformity. This spectrum of signs formed the basis for the CSS which was used in this study. Surprisingly, however, the lung volume (as a proportion of body weight) of affected kittens was not significantly different from a control population of unaffected cats. Larger case numbers and ideally an age-matched control population would allow statistical analysis and verification of these preliminary findings. Results could be further confounded by a compensatory increased depth of respiration seen in affected kittens. More information could be obtained by lung plethysmography but this is not widely available for veterinary patients particularly those with small tidal volumes.

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Three of the ten kittens had at least one previous episode of antimicrobial –responsive dyspnoea. In each case, dyspnoea responded rapidly to the administration of potentiated amoxicillin. The exact site and cause of the presumed infection is not known but this could be caused by ventilation impairment, failure to clear alveolar secretions or other functional abnormalities.

Although only assessed in two of the 10 cases, the sternum did not move significantly during the respiratory cycle with “c” values varying by only 3.16% and 0.68%. This suggests that radiographically determined VI should be relatively constant independent of the respiratory phase at which they were taken.

There was reasonable correlation between radiographically determined and CT-determined VI and FSI, CT consistently gave a lower value for the VI with a mean difference of 0.53 and FSI calculated from CT images tended to be higher than the value calculated from radiographic measurements. The mean difference in FSI was 0.83 but there was a significant association between the variation and the value of the FSI. These findings suggest that separate reference intervals for normality and severity of VI and FSI are appropriate depending on the imaging modality used but that an appropriate reference interval for CT-calculated FSI can be inferred from the published radiographic FSI values.

No significant concurrent musculoskeletal deformities were identified in any of the affected kittens. In each case the sternum started to deform in the caudal half and the deformity was dorsal but also lateral in 5/10 cases with 4/5 being deviated to the right hemithorax. The case with sinistral deviation of the xiphoid was the cat with situs inversus. The cause of this lateralisation away from the heart is uncertain but possible

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explanations would include displacement of the caudally deviated sternebrae by the heart and/or traction from the diaphragmatic crura during development.

Cardiac perforation is a recognised complication of placing a ventral corrective splint.[12] The deformed sternum was judged to be in contact with either the heart or the caudal vena cava in 9/10 cases with the 10th case having a safe corridor for suture placement of only 2mm. Having demonstrated how close the dorsal sternebrae were to the heart in all our surgical cases, we modified our surgical technique accordingly. No intraoperative complications were encountered and no postoperative complications relating to this approach were seen.

VI and FSI are useful for initial screening of cases into an anatomic severity category - mild, moderate or severe but they do not appear to be useful for determining whether cases with moderate to severe anatomic defects are likely to have severe clinical signs. This would imply that there may be other factors beyond simple musculoskeletal deformity which are contributing to the severity of the clinical signs observed. Cats with lateral deviation of the xiphoid seemed to be associated with a lower clinical score than those kittens with a midline deviation. It has been suggested that clinical symptoms of PE in people may be partially due to a direct compressive or restrictive effects of the displaced sternebrae on the heart itself.[13] Athletic performance is compromised by the inability of the heart to increase diastolic volume to meet increased oxygen demands and direct compression of the right side of the heart is considered to be an indication for surgery in people.[5,13] It is possible that clinical signs seemed to be more severe in cats with a midline pectus deformity due to a similar mechanism whereas the kittens with a lateralised defect had more space available for the heart to increase diastolic

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volume as required. Cardiovascular compromise may therefore be a more significant driver of clinical signs associated with PE in kittens than altered pulmonary function. This could be why case J, that had a midline sternal deviation, had severe clinical signs despite a "moderate" VI (7) and it may be that a different threshold (higher VI) should be used when deciding if kittens with midline defects should undergo surgery.

One case (A) developed significant postoperative furosemide-responsive dyspnoea and then died at the time of cast removal. The apparent initial response to diuretics is suggestive of pulmonary oedema that could be caused either by pulmonary re-expansion, concurrent cardiovascular disease or pulmonary hypertension.[14] Although no significant concurrent cardiovascular disease was detected on the initial CT scan, this modality is not as sensitive as echocardiography when assessing cardiac function. The cause of death at the time of cast removal remains unknown as no post-mortem analysis was permitted.

All cases that survived showed full resolution of clinical symptoms with no exercise intolerance or episodes of dyspnoea reported at the time of follow up. Whilst we used a combination of VI and CSS to determine which cases should benefit from surgery, there was no control population for which treatment was intentionally withheld in order to demonstrate a difference in postoperative outcome as this would have been unethical. We suspect that many cases of severe PE are euthanased due to perceived poor prognosis and financial concerns about treatment costs. This, and the rarity of the condition resulted in only low numbers of cases being recruited despite internet based advertising for case enrolment. We are therefore limited to making broad recommendations about patient selection and treatment efficiency. In our study,

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patients were selected for surgery based on VI and clinical signs. All cases had a sternal cast maintained for 4 weeks and all cases that survived are currently asymptomatic at a mean follow up of 15 months. One of the risks of uncorrected PE is the development of pulmonary hypertension and right side heart failure which the authors have observed in multiple cases < 12mths old. It is possible that some of our cases could develop respiratory symptoms at a later stage and we intend to publish longer term follow up (5 year) data when available.

In summary, conventional radiography yields reasonable approximations of CT-determined VI and FSI. CT was useful in determining the presence/absence of safe corridors for circumsternal suture placement leading to a minor modification of the surgical approach employed for ventral cast placement. CT also allowed detection of cats with midline sternal deviation which may be at risk of developing more severe clinical signs due to diastolic restriction despite relatively mild skeletal deformity. Ten to 15 week old kittens with severe deformity as judged by VI and with compatible clinical signs can be treated by placement of a sternal splint for a 4 week period which can be associated with an excellent medium term outcome.

Funding Statement

This research received no grant from any funding agency in the public, commercial or not-for-profit sector

Conflict of Interest

The authors declare that there is no conflict of interest.

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