Comparison of standard T2-weighted turbo spin echo and volumetric interpolated breath-hold examination magnetic resonance imaging sequences in the assessment of articular process dysplasia in Pug dogs with thoracolumbar myelopathy

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Abstract

**Background:** Retrospective study to compare the classification, as normal, hypoplastic or aplastic, of thoracic (T10-T13) caudal articular process (CAP) morphology in Pug dogs with a thoracolumbar myelopathy as normal, hypoplastic or aplastic, between T2 weighted Turbo Spin Echo (T2W-TSE) and Volumetric Interpolated Breath-hold Examination (VIBE) Magnetic Resonance Imaging (MRI) sequences, in comparison to Computed Tomography (CT). We hypothesised a stronger agreement for VIBE in comparison to T2W-TSE.

**Results:** Diagnostic accuracy of T2W-TSE was inferior to VIBE for aplastic (60%, 95% CI 0.561 – 0.639) versus 78%, 95%CI 0.744 - 0.815) hypoplastic (44%, 95%CI 0.427 – 0.452 versus 62.5%, 95%CI 0.595 - 0.655) and normal CAP (70%, 95%CI 0.655 – 0.744 versus 87% 95%CI 0.848- 0.892). Superior accuracy of classification using VIBE versus T2W-TSE sequences using the McNemar Chi squared test was significant for aplastic (p= 0.0002) and normal CAP (p=0.004). VIBE sequences had a sensitivity of 96% and specificity of 75% and with T2W-TSE imaging sensitivity 81% and specificity of 75%.

**Conclusion:** Three-dimensionally reconstructable VIBE sequences were significantly more accurate than traditional T2W-TSE MRI sequences in classifying CAP morphology, which should reduce the need for CT for pre-operative assessment.

Background

Pug dogs are a screw-tailed dog breed over-represented for thoracic vertebral malformations, including caudal articular process (CAP) dysplasia in the caudal thoracic region (1) CAP morphology classification has previously been defined, with hypoplasia being the partial absence of the CAP and aplasia as the complete absence of the CAP (2). These malformations are implicated in the development of pia-arachnoid fibrosis, sub-arachnoid diverticula, and constrictive myelopathy in the thoracolumbar region of T10-L1 (3, 4). Vertebral stabilisation has been recommended in the management of these diseases, given the need to remove the dorsal lamina and inter-arcuate ligament to access the vertebral canal for spinal cord durotomy (5). Traditionally, complete assessment of articular process morphology and in-silico surgical planning requires computed tomography (CT) scans following Magnetic Resonance Imaging (MRI). Performing CT imaging prolongs anaesthetic time, has financial implications, increases the number of transfers under anaesthesia, requires availability of two cross sectional imaging modalities in one hospital and administers a radiation dose to dogs. MRI is more sensitive to evaluate the primary spinal cord disease process showing parenchymal detail which cannot be evaluated with CT. We therefore considered if MRI sequences could be used for CAP classification and surgical planning in order that the requirement for CT in these patients could be reduced/eliminated.

Three-dimensional (3D) volumetric MRI acquisitions have the advantage of improving through plane spatial resolution and generate high-quality reformatting to yield multiplanar images from the original dataset. Volumetric interpolated breath-hold examination (VIBE) is a form of volumetric imaging using
fast 3D gradient-echo sequences that produces $T_1$ images and was first introduced by Rofsky in 1999 (6). It has the advantage of improving Z-axis resolution, which makes it possible to obtain high-quality multiplanar and 3D reconstruction images. VIBE has been effectively used in breast (7), human abdominal (8) and musculoskeletal imaging (9) with use in veterinary medicine limited for assessing facial neuritis (10) and skull fractures (11). Hecht et al (11) found VIBE imaging was highly accurate in identifying post mortem skull fractures in animals. MRI of the vertebral column for fracture identification has been previously compared to CT and moderate interobserver agreement was found, but up to 79% of fractures in some vertebrae were not recognised, however this was using only single plane MRI sequences (12).

The aim of this study was to quantify the accuracy of two MRI sequences, VIBE and T2W-TSE, when compared to the current gold standard of CT. The null hypothesis being:

There will be stronger agreement between VIBE sequences and CT in comparison to standard T2W-TSE and CT, in the assessment of CAP dysplasia in the T10-T13 region.

**Results**

11 pugs fit the inclusion criteria, contributing a total of 72 CAP for classification by 4 observers (1 ECVN resident, 2 boarded veterinary neurologists and 1 boarded veterinary diagnostic imager). The mean age of pugs was 96 months (range 52–140). The mean weight was 8.1kg (range 4.5–11.5).

16 CAPs were classified as normal, 12 hypoplastic and 44 aplastic using CT. Table 1 shows each reviewers number and percentage agreement with CT for both VIBE and MRI sequences of each classification of CAP. Reviewer 1 correctly classified (VIBE/T2W-TSE) 13 /7 normal: (81%/43%), 7 /5; (58%/41%) hypoplastic and 39/42; (88%/95%) aplastic CAP's, Reviewer 2 correctly classified 14/12; (87%/75%) normal, 9/6 (75%/50%) hypoplastic and 41/31; (93%/70%) aplastic CAP's, Reviewer 3 correctly classified 16/13; (100%/81%) normal, 6/5; (50%/41%) hypoplastic and 40/17; (90%/38%) aplastic CAP's. Reviewer 4 correctly classified 13/13; (81%/81%) normal, 8/5; (66%/41%) hypoplastic and 19/19; (43%/43%) aplastic CAP's.
Table 1
Reviewer number and percentage agreement with CT using T2W-TSE and VIBE sequences.

<table>
<thead>
<tr>
<th>Reviewer</th>
<th>CT classification of CAP</th>
<th>VIBE</th>
<th>T2W-TSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Normal</td>
<td>13 (81%)</td>
<td>7 (43%)</td>
</tr>
<tr>
<td></td>
<td>Hypoplastic</td>
<td>7 (58%)</td>
<td>5 (41%)</td>
</tr>
<tr>
<td></td>
<td>Aplastic</td>
<td>39 (88%)</td>
<td>42 (95%)</td>
</tr>
<tr>
<td>2</td>
<td>Normal</td>
<td>14 (87%)</td>
<td>12 (75%)</td>
</tr>
<tr>
<td></td>
<td>Hypoplastic</td>
<td>9 (75%)</td>
<td>6 (50%)</td>
</tr>
<tr>
<td></td>
<td>Aplastic</td>
<td>41 (93%)</td>
<td>31 (70%)</td>
</tr>
<tr>
<td>3</td>
<td>Normal</td>
<td>16 (100%)</td>
<td>13 (81%)</td>
</tr>
<tr>
<td></td>
<td>Hypoplastic</td>
<td>6 (50%)</td>
<td>5 (41%)</td>
</tr>
<tr>
<td></td>
<td>Aplastic</td>
<td>40 (90%)</td>
<td>17 (38%)</td>
</tr>
<tr>
<td>4</td>
<td>Normal</td>
<td>13 (81%)</td>
<td>13 (81%)</td>
</tr>
<tr>
<td></td>
<td>Hypoplastic</td>
<td>8 (66%)</td>
<td>5 (41%)</td>
</tr>
<tr>
<td></td>
<td>Aplastic</td>
<td>19 (43%)</td>
<td>19 (43%)</td>
</tr>
</tbody>
</table>

As summarised in Table 2; Mean accuracy for T2W-TSE sequences between all reviewers was 60.7%; for individual categories normal 70% (CI 95% 0.655–0.744), hypoplastic 44% (CI 95% 0.427–0.452), aplastic 60% (CI 95% 0.561–0.639) Mean accuracy between all reviewers for VIBE was 80.5%, normal 87% (CI 95% 0.848–0.892), hypoplastic 62.5% (CI 95% 0.595–0.655) and aplastic 78% (CI 95% 0.744–0.815).

The McNemar chi squared test revealed an overall test statistic of 23.7 with an odds ratio 0.3 and p value of 0. For aplastic CAP, the test statistic was 12.44 with odds ratio of 0.369 and p = 0.0002. For hypoplastic CAP, the test statistic was 1.7 with odds ratio 0.5 and p value 0.09. For normal CAP, the test statistic 6.66667, with odds ratio of 0.15 and p- value = 0.004.

Table 2
Percentage accuracy of reviewers on classification of CAP using T2W-TSE and VIBE sequences

<table>
<thead>
<tr>
<th>% accuracy of classification of CAP</th>
<th>normal</th>
<th>hypoplastic</th>
<th>aplastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIBE</td>
<td>87* CI 95% (± 2.193)</td>
<td>62.5 95% CI (± 3.03)</td>
<td>78* CI 95% (± 3.531)</td>
</tr>
<tr>
<td>T2W-TSE</td>
<td>70* CI 95% (± 4.464)</td>
<td>44 CI 95% (± 1.273)</td>
<td>60* CI 95% (± 3.899)</td>
</tr>
</tbody>
</table>
*denotes significant difference between T2W-TSE and VIBE accuracy by reviewers for CAP classification.

Kappa statistics for T2W-TSE interobserver agreement for aplastic / hypoplastic / normal were respectively 0.06 95% CI for free-marginal kappa [-0.12, 0.24] / 0.00 95% CI for free-marginal kappa [-0.34, 0.34] / -0.08 95% CI for free-marginal kappa [-0.35, 0.18]. These results are interpreted as slight / slight / no agreement for the respective categories.

Kappa statistics for VIBE interobserver agreement for aplastic / hypoplastic / normal were respectively 0.61 95% CI for free-marginal kappa [0.42, 0.79] / 0.11 95% CI for free-marginal kappa [-0.26, 0.48] / 0.75 95% CI for free-marginal kappa [0.49, 1.00]. These results are interpreted as substantial / slight / substantial agreement for their respective categories.

Comparing sensitivity and specificity to identify abnormal CAP classifications, CAP on VIBE sequences were classified with sensitivity of 96% and specificity of 75%, whereas T2W-TSE sequences had sensitivity of 81% and specificity of 75%.

**Discussion**

This study allows us to accept the hypothesis that ‘there would be stronger agreement between VIBE sequences and CT in comparison to standard T2W-TSE and CT, in the assessment of articular process malformations in the T10-T13 region.’ It also confirmed a higher accuracy and interobserver repeatability of VIBE studies compared to T2W-TSE for correct classification of caudal articular processes. This is consistent with previous findings in assessment of other small animal bony changes, such as Hecht et al (11) who found a 93.9% agreement of skull fracture identification with VIBE to CT this shows also transferrable use of MRI in looking at bone morphology. Our findings suggest that VIBE sequences could potentially be considered in place of CT to identify CAP abnormalities. Considering the superior sensitivity of VIBE sequences (sensitivity of 96% and specificity of 75%) abnormal CAP are unlikely to be misdiagnosed.

The McNemar statistical test shows a significant difference in accuracy of classification of normal and aplastic CAP, however for categorisation of hypoplastic CAP’s there is no significant difference between VIBE and T2W-TSE sequences despite a higher accuracy of identification of hypoplastic facets with VIBE compared to T2W-TSE. The lack of significance in the hypoplastic group may be due to the smaller number of hypoplastic CAP in the study causing this number to fail to reach significance. Hypoplastic CAP are also more difficult to define as a small amount of CAP being present can be challenging to identify on any sequence.

Our finding of 77.7% CAP abnormalities in the T10-L1 region in our study is also consistent finding with previous studies (1). Only one patient contributed only normal CAP in our study, with the remaining 8 normal facets coming from 3 of our other patients.
Limitations of this study include its retrospective nature, meaning that imaging protocols were not standardised and therefore the orientation angle of sequence to the CAP may affect the ability to correctly interpret T2W-TSE sequences, which cannot undergo 3D reconstruction. However, it is standard for transverse MRI sequences to be obtained perpendicular to the spinal cord in our hospital and therefore this effect was hopefully minimised. The number of CAP included in the study could be increased to strengthen the power of this study. The observers in this study were 2 ECVN diploma holding specialists and 1 ECVN resident and an ECVDI diploma holding specialists who use MRI frequently in clinical practice, this means extrapolation to others with experience in MRI interpretation would be highly likely.

Pug dogs were selected for this study, given the known propensity for CAP in this region. Application of the principle to other breeds is unknown and may be more challenging for smaller breeds but further study could be considered to test this.

Our CAP reviewers subjectively commented that they had spent longer deciding the categorisation of CAP’s with T2W-TSE compared to VIBE images and this could be an important variable to be assessed in future studies as it would add weight to the benefits of using VIBE sequences.

Further investigations to understand if VIBE sequences could be used for in-silico surgical planning, notably in the production of patient-specific 3D surgical drill guides, as is the case in total knee arthroplasty in humans, where studies have shown no significant difference in accuracy of implant placement using MRI and CT imaging for in-silico planning (13, 14). This would further negate the need for CT, reducing anaesthesia time, transfers under anaesthesia and reduce radiation exposure of these patients.

**Conclusions**

Our current study showed that three-dimensionally reconstructable VIBE sequences were significantly more accurate than traditional T2W-TSE MRI sequences in classifying CAP morphology, which could support the use of MRI assessment of CAP for decisions on the necessity for stabilisation and reduce the need for CT as part of the pre-operative assessment.

**Methods**

An estimated, a priori sample size for this study indicated that, between 60–120 observations (8–15 dogs) were required, with a significance level of 5% and power of 80%. This calculation assumed a proportion of agreement under the null hypothesis between 0.80 and 0.85, and the expected difference between two proportions of agreement of the null and alternative hypothesis to be between 0.10–0.15.

An ethics proposal of protocols was submitted to and approved by the CVS ethical review board (number CVS-2022-016). Data was collected as part of clinical investigations into Pug dogs presenting with signs of T3-L3 myelopathy and consent was gained from their caregivers prior to these investigations.
This was a retrospective case-controlled series. The practice electronic patient database (Robovet, Covetrus, v.5.53) was searched for Pug dogs presenting with thoracolumbar myelopathy from 2020–2022. These were then each searched for the inclusion criteria of MRI T2W-TSE sequences in sagittal and transverse plains, VIBE sequences and CT including CAP from T10-L1. Patients were excluded if they had an imaging diagnoses affecting articular process morphology i.e., osteolytic/productive lesions related to suspect spinal neoplastic, inflammatory, or infectious disease or if there were vertebral body malformations resulting in significant kyphoscoliosis in caudal thoracic region.

MRI sequences were randomised, and patient details blinded to the observer. Each observer received training on the definition of normal, hypoplastic and aplastic CAP and was shown example CT images as shown in Fig. 1. and then classified each CAP in T2W-TSE and VIBE sequences as normal, hypoplastic, or aplastic as shown in Fig. 2. The primary observer then reviewed CT imaging and classified each CAP, and this was used as the control.

Figure 1: CT images of a) normal b) hypoplastic and c) aplastic CAP.

This was provided to observers prior to MRI assessment as an example of normal, hypoplastic and aplastic CAPs.

Figure 2: VIBE and T2W-TSE images of vertebral morphology: a) aplastic CAP, b) hypoplastic c) normal).

All MRI sequences were performed using a high field system (1.5 Tesla Siemens Magnetom Essenza) with patients anaesthetised and positioned in dorsal recumbency. T2W-TSE sequence slice thickness 3mm, matrix 204x834, field of view 146 x 180, VIBE slice thickness 1mm, matrix 460x512, field of view 190x190, phase field of view 100, slice over sampling 100, flip angle 12, averages 2.

CT of the entire spine was performed using a 16-slice Siemens Somatom scope CT scanner with patients under anaesthesia in sternal recumbency. A bone algorithm window was used for reconstruction of images in 3D for control analysis of caudal articular process. Total mAs 5580, kVp 130, DLP 486, tube rotation time was 0.8 seconds, slice thickness 0.75mm.

**Statistical analysis:**

Overall percentage agreement and percentage agreement by category will be reported and compared using a McNemar chi-squared test and a P value of less than 0.05 was accepted as significant.

The kappa statistic was be used to assess agreement of observer categorisations of the 2 MRI sequences. A zero value of Kappa indicates no agreement above that expected by chance, a value of 1 indicates perfect agreement and a negative value indicates agreement worse than that expected by chance.

The sensitivity and specificity of the two MRI methods to identify abnormal CAP classifications will be reported, in respect to CT as the gold standard.
Qualitative/descriptive data will be presented as count numbers and percentages.

**Abbreviations**

CAP; Caudal articular process, CT; Computed Tomography, MRI; Magnetic Resonance Imaging, T2W-TSE; T2 weighted Turbo Spin Echo, VIBE; Volume Interpolated Breath-hold Examination

**Declarations**

Ethics approval and consent to participate

Ethics approval was gained from the Consolidated Veterinary Services internal ethical review board prior to commencement of the study. Ethics number CVS-2022-016.

Informed owner consent was received for all diagnostic procedures prior to commencement for all animals and these were carried out in accordance with best practice veterinary care and following RCVS guidelines.

Consent for publication

Informed owner consent for publication of images was gained for all animals.

Availability of data and materials

The materials and data not presented in this manuscript are available from the corresponding author upon request.

Competing interests

The authors declare that they have no competing interests.

Funding

The authors declare they received no funding for the study.

Authors’ contributions

CD was responsible for the concept. CD and EG designed the study. EG collected and analysed the data. All authors read and approved the final manuscript.

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References


Figures

Figure 1

CT images of a) normal b) hypoplastic and c) aplastic CAP.

This was provided to observers prior to MRI assessment as an example of normal, hypoplastic and aplastic CAPs.
Figure 2

VIBE and T2W-TSE images of vertebral morphology: a) aplastic CAP, b) hypoplastic c) normal).