Rabbits have aradicular (lacking true roots), hypsodont (long crowned with enamel extending past the gingival margin), and elodont (erupting throughout life) dentition with lophodont molar and premo- lar teeth (having enamel ridges on the occlusal surface). The dental formula of the permanent set of 28 teeth that erupt during the first 5 weeks of life is I 2/1, C 0/0, P 3/2, M 3/3. The structure and physiology of rabbits’ teeth are necessary to overcome abrasion caused by a coarse diet. Any process that interferes with the normal eruption, wear, or support structure of the teeth can lead to acquired dental disease.

Rabbits with dental disease often have extraoral clinical signs including anorexia or hyporexia, lacrimal discharge, nasal discharge, exophthalmia, facial hair loss, soft tissue and bony swellings, and gastrointestinal ileus. Intraoral signs can include ptyalism, halitosis, tooth discoloration, sharp lingual or buccal dental points, mucosal ulceration, clinical crown elongation, and malocclusion. Clinical crown elongation results from the overgrowth of the portion of a tooth above the gingival margin and may be associated with sharp dental points. Reserve crown (or apical) elongation is a lengthening of the portion of the tooth below the gingival margin in the opposite direction from normal eruption. Elongation of the apices is a finding that can be difficult to assess on physical examination alone but may manifest as bony protrusions from the ventral surface of the mandibles. A potentially more sensitive way to determine elongation of the apices is by examination of skull radiographs, where an objective method has been proposed for assessing the presence of apical elongation.

Acquired dental disease in rabbits, characterized by features such as overgrowth of clinical

**OBJECTIVE**

To characterize the CT findings and epidemiological features of acquired dental disease in rabbits.

**ANIMALS**

100 client-owned rabbits (*Oryctolagus cuniculus*).

**PROCEDURES**

Medical records were searched to identify rabbits that underwent skull CT for any reason from 2009 to 2017. History, signalment, and physical examination findings were recorded. The CT images were reevaluated retrospectively for evidence of dental disease and graded according to a previously described system (from 1 [no evidence of disease] to 5 [severe dental disease]) for acquired dental disease in rabbits, and an overall (mean) grade was assigned. Descriptive analyses were performed. Factors were assessed for associations between dental disease grade and malocclusion stage.

**RESULTS**

Common findings included premolar or molar tooth curvature in transverse (n = 100 rabbits) and sagittal (95) planes, apical elongation of premolar or molar teeth (99), sharp dental points (93), deformation of the mandibular canal (82), and periodontal ligament space widening (76). Acquired dental disease was classified as grade 1 (n = 2 rabbits), 2 (60), 3 (14), 4 (4), or 5 (20). Most CT findings were significantly correlated with each other. Agreement of grades was fair between left- and right-sided quadrants and between maxillary and mandibular quadrants. Age was associated with increasing dental disease grade and malocclusion stage (proportional ORs, 1.21 and 1.32/y, respectively).

**CONCLUSIONS AND CLINICAL RELEVANCE**

Fair agreement in disease grades between dental quadrant pairs indicated a degree of asynchrony in the development of dental disease. Findings suggest premolar or molar tooth curvature in a sagittal plane, subtle elongation at premolar or molar tooth apices, and mandibular canal deformation should be added to the grading system.
crown, reserve crowns, or both; malocclusion; and periodontal disease with or without secondary periapical abscess formation, has been previously described and termed PSADD, although information published to date supporting the existence of a progressive syndrome is largely based on skull and radiographic evaluations.2,5,7 According to the previously published grading scale, acquired dental disease in rabbits can be graded on a scale of 1 to 5.2,8,9 Grade 1 is considered to be normal. Grade 2 is often subclinical disease characterized by elongation at the apices of teeth resulting in palpable hard swellings along the ventral aspect of the mandibles and deterioration in tooth quality. Grade 3 involves acquired malocclusion resulting from loss of supporting bone and subsequent alterations in the position, shape, and structure of teeth; a range of clinical signs from sharp dental points to loss of alveolar bone that results in periodontal ligament space widening and predisposes to apical abscess formation can develop.3,5,10 Periapical abscesses have been described as common in rabbits with the higher grades of dental disease according to this system but can occur at any time.2,7 Acquired malocclusion, which is found in rabbits with grades of acquired dental disease ≥3, follows a general pattern and has been also described in 3 stages (stage 1: curvature of mandibular fourth premolar, first molar, and sometimes second molar teeth that may result in sharp points on the lingual aspects; stage 2: curvature of maxillary second and third premolar teeth that may result in sharp points on the buccal aspects; and stage 3: rotation, curvature, and elongation of the mandibular second and third molar teeth).8,9 For grade 4 acquired dental disease, cessation of tooth growth can result from resorption and destruction of tooth germinal centers at the apices. Grade 5 is the most severe disease category, with findings including osteomyelitis with abscess formation, often caused by penetration of the periosteum by 1 or more tooth apices.2,8,9 Although these changes in dentition have been described as having a chronological progression, individual teeth or quadrants can be unaffected; therefore, it is possible to see a patient with both normal and abnormal dentition.5,8

Results of previous studies11,12 have suggested that CT may provide more detail and have greater accuracy for determining diagnosis, prognosis, and treatment for dental disorders in rabbits, compared with standard radiography. The use of CT allows evaluation of structures without superimposition of adjacent anatomy, and multiplanar reconstruction allows the operator to evaluate each structure in various planes, thus providing a useful tool for assessment of the 3-D directional changes and elongation that are found with malocclusion.8,13 Although there have been reports9,14,15 describing CT findings in rabbits with dental disease, to the authors’ knowledge, there are no publications in which epidemiological findings related to acquired dental disease have been described and categorized in a large sample of rabbits.

The goal of the study reported here was to describe CT characteristics of dental disease and evaluate the distribution of those characteristics for a large sample of rabbits. We further set out to relate the CT findings with the previously described grades of acquired dental disease in rabbits. The hypotheses were that the CT findings in affected rabbits, including findings related to malocclusion, would correspond with the grading scheme used for assessment of the previously described PSADD; be evenly distributed in the study sample; and occur with a moderate degree of asynchrony in all dental quadrants in individual rabbits.

Materials and Methods

Case selection

An electronic search of the medical records at the University of California-Davis William R. Pritchard Veterinary Medical Teaching Hospital was performed to identify rabbits that underwent MDCT of the skull from January 1, 2009, to July 31, 2017. A search was specified for lagomorphs only, and search terms included skull CT, dental CT, malocclusion, and periapical abscess. Rabbits with conventional skull CTs available for retrospective review were included in the study regardless of the reason for CT and whether clinical signs of dental disease were present. When a rabbit had multiple CT evaluations performed, only the earliest imaging data were used.

Medical records review

Information extracted from each medical record included signalment (age, breed, and sex and reproductive status [sexually intact, spayed, or neutered]), pertinent history, clinical signs related to dental disease, and oral examination findings. Rabbits were categorized on the basis of breed size (when the information was available) as being dwarf or miniature, standard sized, or giant. Mixed-breed rabbits were classified on the basis of the predominantly listed breed. Pertinent history included the reasons for evaluation and any dental procedures performed within 1 month prior to the CT date. Rabbits were categorized as undergoing evaluation for signs that could be attributed to dental disease or nondental disease on the basis of the main clinical problem reported by owners and physical examination results; furthermore, each rabbit considered to have signs compatible with dental disease was categorized as having clinical signs that were oral, extraoral, or both.

MDCT examinations and image review

All images were acquired by use of an MDCT scanner2 with patients in sternal recumbency un-
under sedation or general anesthesia. The preferred acquisition method included a scan slice thickness of 0.6 mm, with a thickness of 1.25 mm used in some cases. At least 1 scan was acquired with a high-frequency (bone) convolution kernel, and when contrast medium was administered, images were acquired with a medium-frequency (soft tissue) kernel.

Commercial computer software\(^b\) was used to reevaluate CT images in transverse, dorsal, and sagittal planes with multiplanar reconstruction. The CT images were retrospectively reviewed by a board-certified veterinary radiologist (KLP) and a veterinary student (CAA); the reviewers were not blinded to the final diagnosis at time of image review. Intravenous administration of contrast medium\(^c\) (880 mg/kg [400 mg/lb]) for CT scans was recorded. All images were evaluated for the presence or absence of malocclusion of the incisor teeth, incisor tooth apical elongation, premolar or molar tooth curvature (in transverse and sagittal planes), sharp dental points, and premolar or molar tooth clinical crown and apical elongation, as well as apical malangulation, pulp cavity narrowing or widening, central enamel line thinning, interproximal space widening, periodontal ligament space widening, lamina dura loss, periapical abscesses (defined as periapical lucencies with alveolar expansion), cortical lysis, periosteal reactions, tooth resorption, tooth hyperattenuation, tooth fractures, soft tissue abscesses, and alveolar bula penetration by the apices of teeth. Surrounding anatomic structures, including the mandibular canals, recesses of the maxillary sinuses, and lacrimal canals, were evaluated for abnormalities, and lymph node enlargement, evidence of nasal disease, and turbinate loss were noted. A representative sagittal plane image illustrating normal occlusion of premolar and molar teeth, central enamel lines, and pulp cavities is provided (Figure 1).

The grading system proposed by Harcourt-Brown\(^d\) for assessment of the described PSADD was used to classify acquired dental disease for each rabbit on the basis of CT evidence of the described changes. Grades were assigned to each tooth for each quadrant, and a final grade for the quadrant was determined on the basis of the predominant grade noted in that quadrant. The mean of the grades for each quadrant was used to establish the overall grade of acquired dental disease for each rabbit for purposes of the present study. Therefore, an individual rabbit could have a tooth or quadrant classified as grade 5 while the overall grade for the same animal was lower. Additionally, features not originally described in that grading system\(^d\) such as tooth curvature in the sagittal plane and mandibular canal deformation, were assessed but not used in determining the grade. Lastly, all rabbits were scored for acquired malocclusion stage according to the features previously described by Harcourt-Brown.\(^e\) Assessment criteria for each structure or feature evaluated on CT images are provided (Appendices 1 and 2).\(^f\) Variables used to assess severity are provided for reference where applicable, and descriptive results for severity of selected lesions were compiled. However, only the presence or absence of the described features was used in determining frequencies for statistical analysis.

**Statistical analysis**

Age data were found to be normally distributed by use of a \(\chi^2\) normality test with commercial software\(^g\) and were reported as mean ± SD. Categorical data (presence or absence of each CT-detected change) were reported as frequency of occurrence within each grade for acquired dental disease. Descriptive statistics were calculated, and when appropriate, Clopper-Pearson binomial proportions with exact 95% CIs were calculated with online software.\(^h\) Commercial software\(^i\) was used for the remaining statistical analysis. A correlation matrix was completed with Spearman correlation coefficients for all ordinal variables. Because of the large number of comparisons, a Bonferroni adjustment...
was performed for the \( P \) values of the correlation coefficients. The effects of age, sex, reproductive status, size (dwarf-miniature, standard sized, or giant breeds), and lop-eared breed (yes vs no) on acquired dental disease grade and acquired malocclusion stage were investigated with univariate and multiple ordinal logistic regression analysis for ordinal variables and with univariate and multiple logistic regression analysis for binary variables. Assumptions were checked graphically on residual plots. The assumption of proportional odds for the ordinal models was checked against a multivariate mixed logistic model by use of a likelihood ratio test. A similar mixed model was used for repeated measures such as acquired dental disease grades per quadrant with rabbit ID included as a random variable. The degree of correspondence in disease grades between left- and right-sided quadrants and maxillary versus mandibular quadrants was assessed with the Cohen \( \kappa \) statistic as follows: 0.01 to 0.20 = slight agreement, 0.21 to 0.40 = fair agreement, 0.41 to 0.60 = moderate agreement, 0.61 to 0.80 = substantial agreement, and 0.81 to 1.00 = almost perfect agreement. Values of \( P < 0.05 \) were considered significant, including values with a Bonferroni adjustment performed for multiple comparisons.

### Results

### Rabbits

One hundred client-owned rabbits were included in the study. The sample included 12 Holland Lops, 11 Dutch (including Dutch Belted), 6 Mini Rex, 4 dwarves (breed not further specified), 4 Lionheads, 4 Mini Lops, 4 New Zealand Whites, 2...
Californians, 2 Dwarf Lops, 2 English Lops, 2 English Spots, 2 Flemish Giants, and 1 Rex; 17 were described aslop-cared rabbits without further details, 3 were mixed-breed rabbits (including 1 Dwarf Lionhead cross), 1 was an Angora-type rabbit, and 23 were of unknown breeds. Forty-two rabbits were categorized as dwarf-miniature breeds, 28 were considered standard-sized breeds, and 7 were giant breeds; the 23 rabbits of unknown breeding were unclassified. Of 77 rabbits with breed or breed type reported, 42 (55%; 95% CI, 43% to 65%) were dwarf-miniature rabbits. Standard-sized breeds comprised 28 (36%; 95% CI, 26% to 47%) rabbits, and only 7 (9%; 95% CI, 3% to 16%) were giant breeds. Ages for the 98 rabbits with information available ranged from 1 to 10 years (mean ± SD, 5.16 ± 2.34 years). The sample included 62 males and 38 females; most males (51/62 [82%]; 95% CI, 71% to 91%) were neutered, and most females (32/38 [84%]; 95% CI, 69% to 94%) were spayed. Thirty-six of 100 (36%; 95% CI, 26.6% to 45.4%) rabbits were known to have undergone dental procedures prior to CT, including occlusal plane adjustments, clinical crown reductions, reduction of sharp dental points, and dental extractions. Fourteen of those rabbits (14%; 95% CI, 7.9% to 22.4%) had the procedure performed ≤1 month before undergoing CT.

**History and oral examination findings**

Common clinical signs for the 100 rabbits at the time of evaluation included ocular discharge (n = 30 [30%]; 95% CI, 21.2% to 40%), mandibular or maxillary masses (26 [26%]; 95% CI, 17.7% to 35.7%), anorexia or hyporexia (26 [26%]; 95% CI, 17.7% to 35.7%), and nasal discharge (21 [21%]; 95% CI, 13.5% to 30.3%). Less common clinical signs included vestibular signs or head tilt (10 [10%]; 95% CI, 4.9% to 17.6%), a retrobulbar mass causing exophthalmia (10 [10%]; 95% CI, 4.9% to 17.6%), otitis (9 [9%]; 95% CI, 4.2% to 16.4%), rhinitis or upper respiratory infection (8 [8%]; 95% CI, 3.5% to 15.2%), soft tissue swelling (8 [8%]; 95% CI, 3.5% to 15.2%), sneezing (6 [6%]; 95% CI, 2.2% to 12.6%), ptyalism (6 [6%]; 95% CI, 2.2% to 12.6%), and halitosis (5 [5%]; 95% CI, 1.6% to 11.3%). Few rabbits had nasolacrimal obstruction (3 [3%]; 95% CI, 0.6% to 8.5%), bruxism (3 [3%]; 95% CI, 0.6% to 8.5%), or facial nerve paralysis (1 [1%]; 95% CI, 0% to 5.4%). Two (2%; 95% CI, 0.2% to 7%) rabbits had neoplasia, and 2 (2%; 95% CI, 0.2% to 7%) had a history of trauma.

Nine (9%; 95% CI, 4.2% to 16.4%) rabbits had no clinical signs attributable to dental disease. Twenty-nine rabbits (29%; 95% CI, 20.4% to 38.9%) had only intraoral signs, and 27 (27%; 95% CI, 18.6% to 36.8%) had only extraoral signs. Finally, 35 rabbits (35%; 95% CI, 25.7% to 45.2%) had both intraoral and extraoral signs.

**Diagnostic imaging findings**

Most CT images were obtained with 0.6-mm slice thickness (n = 95 rabbits), and the remainder (5) were acquired with 1.25-mm slice thickness. The CT findings for teeth and other related or local structures were summarized by frequency for each overall grade of acquired dental disease (Tables 1 and 2). Almost all dental CT variables were significantly correlated with each other in the correlation matrix, with most having values of $r_s > 0.2$ and $P < 0.001$ (Supplementary Figure S1, available at avmajournals.avma.org/doi/suppl/10.2460/javma.257.3.313). Among CT variables, periodontal...
ligament space widening ($r_s = 0.43; P < 0.001$) and interproximal space widening ($r_s = 0.41; P < 0.001$) were correlated with periapical abscess formation.

The only variable significantly associated with increasing acquired dental disease grade was rabbit age, with 21% greater odds of having a score 1 point higher/y (proportional OR, 1.21/y; 95% CI, 1.02 to 1.44; $P = 0.031$). There was no effect of any evaluated variable on the grades for individual dental quadrants, suggesting that age was associated with only the overall grade. Acquired dental disease grades were similar among the 4 quadrants (all $P > 0.05$). Overall, there was only fair agreement of grades between left-sided and right-sided quadrants ($\kappa = 0.35; P < 0.001$). A similar result was observed when grades for both maxillary quadrants were compared with those for both mandibular quadrants ($\kappa = 0.23; P < 0.001$).

None of the investigated variables was associated with the presence of malocclusion of the incisor teeth (all $P > 0.05$). For malocclusion stage, the effect of age (proportional OR, 1.32/y; 95% CI, 1.05 to 1.68; $P = 0.027$) was similar to that for dental disease grade.

Premolar or molar tooth curvature, assessed in the transverse and sagittal planes, was seen to some degree in 100 (100%) and 95 (95%) rabbits, respectively, when all grades of acquired dental disease were considered together (Table 1). Examples of various severities in curvature are shown (Figures 2 and 3). Maxillary premolar tooth curvature in a sagittal plane was commonly seen in rabbits with grade 2 disease (54/60 [90%]; 95% CI, 82% to 97%), whereas mandibular premolar tooth curvature in this plane was seen in 16 (27%; 95% CI, 15% to 38%) and mandibular molar tooth curvature in this plane was seen in only 8 (13%; 95% CI, 5% to 22%) rabbits with this disease grade. Mandibular molar tooth curvature in a sagittal plane was seen in 6 of 14 (43%; 95% CI, 17% to 69%) rabbits with grade 3, 3 of 4 (75%; 95% CI, 33% to 100%) rabbits with grade 4, and 11 of 20 (55%; 95% CI, 33% to 77%) rabbits with grade 5 disease. Maxillary molar tooth curvature in a sagittal plane was seen in only rabbits with grade 5 disease (3/20 [15%]; 95% CI, 0% to 31%).

Eighty-three rabbits (83%; 95% CI, 74.2% to 89.8%) had stage 2 malocclusion, indicating they had curvature of the maxillary second and third premolar teeth in the transverse plane. Sixty-seven of those 83 (81%; 95% CI, 71% to 89%) rabbits also had curvature of maxillary molar teeth in this plane.

Almost all rabbits (99/100 [99%]; Table 1) had some degree of elongation of the apical aspects of premolar or molar teeth, and 76 (76%; 95% CI, 68% to 84%) rabbits had teeth that penetrated the alveolar bulla (maxilla) or mandibular cortex. One of 2 rabbits assigned a grade of 1 had signs of elongation at the apices of mandibular premolar and mo-
Figure 4—Transverse-plane CT images depicting apical elongation (ie, lengthening of the reserve crown in the opposite direction from normal eruption) of the mandibular third molar teeth in rabbits. A—Mild apical elongation with associated thinning of the mandibular cortices (asterisk with arrows). B—Moderate apical elongation with perforation of the ventromedial mandibular cortices by tooth apices (dagger with arrows). C—Severe apical elongation with perforation of the ventromedial mandibular cortices. The germinal center regions extend completely through the cortices (double dagger with arrows).

Figure 5—Transverse-plane CT images revealing sharp dental points on the buccal aspects of maxillary teeth in rabbits. A—Mild dental point on the left maxillary fourth premolar tooth (asterisk). B—Moderate dental point on the left maxillary third premolar tooth (dagger). C—Severe dental point on the left maxillary first molar tooth (double dagger; a mild dental point is also present on the right mandibular first molar tooth in this image).

Figure 6—Transverse-plane CT images depicting mandibular canals passing ventral to the mandibular teeth in rabbits. A—A normal mandibular canal that is round and hypoattenuating (asterisk with arrow) is seen in an image obtained at the level of the mandibular third premolar teeth. B—Apical elongation of the mandibular third premolar teeth with resultant compression or flattening of the mandibular canal (dagger with arrow). C—Severe resorption and fragmentation of the mandibular third premolar teeth with effacement of the mandibular canal.
lar teeth and minor thinning without penetration of the ventromedial mandibular cortex. Images depicting apical elongation are provided (Figure 4). The mandibular third premolar teeth were the most commonly affected teeth (97/100 [97%] rabbits) and the only teeth with detectable elongation in rabbits with dental disease grades ≤ 2. These teeth compromised the medial or lingual aspect of the mandibles in each case. Penetration of both the maxillary and mandibular cortices was seen in 24 of 60 (40%; 95% CI, 28% to 52%) rabbits with grade 2 dental disease, whereas thinning of both cortices was seen in 17 (28%; 95% CI, 17% to 40%); 36 (60%; 95% CI, 48% to 72%) rabbits in this category had penetration of the overlying cortical bone by ≥ 1 tooth, whereas all rabbits assigned grades ≥ 3 had tooth apices that penetrated maxillary cortices, mandibular cortices, or both.

Examples of sharp dental points in rabbits are shown (Figure 5). Of 93 rabbits with this finding, 19 (20%; 95% CI, 13% to 30%) had reverse dental points owing to reverse angulation of the teeth (ie, maxillary premolar and molar teeth with lingual points or mandibular teeth with buccal points). Sixteen of these 19 rabbits were assigned dental disease grades ≥ 3.

Deformation of the mandibular canal was identified in 82 of 100 (82%) rabbits (Table 2; Figure 6). This abnormality was more common in rabbits with higher grades of dental disease, affecting 1 of 2 rabbits with grade 1 disease, 53 of 60 (88%) with grade 2 disease, and 38 of 38 (100%) with grades of 3 to 5. Subjectively, mandibular canal compression or deformation was more common in rabbits with low grades of disease, whereas mandibular canal effacement was seen in high grades (ie > 3).
Twenty-four rabbits were found to have malocclusion of incisor teeth (Table 1), and 15 of these 24 (63%; 95% CI, 43% to 82%) rabbits had concurrent premolar or molar tooth clinical crown elongation. Twelve of these 24 (50%; 95% CI, 30% to 70%) rabbits were of dwarf-miniature breeds, and 7 of these 12 rabbits had concurrent premolar and molar tooth clinical crown elongation.

Seventy-six of 100 (76%) rabbits had signs of periodontal ligament space widening (Table 2; Figure 7). These included 1 of 2 rabbits with grade 1 and most rabbits with other grades of dental disease (grade 2, 39/60; grade 3, 13/14; grade 4, 4/4; and grade 5, 19/20).

Sixty-one rabbits had periapical lucencies with alveolar expansion (Table 1). Of these 61 rabbits, 39 (64%; 95% CI, 51% to 76%) had abscesses extending into the surrounding structures and soft tissues (Figure 8). Forty-three (70%; 95% CI, 59% to 82%) had associated lysis affecting the mandibular cortex, whereas only 19 (31%; 95% CI, 20% to 43%) rabbits had associated lysis affecting the maxillary cortex. In most rabbits with grade 2 acquired dental disease that had periapical lucencies and alveolar expansion, only the mandibles were affected (14/24 [58%; 95% CI, 37% to 78%]; 7 had only the maxilla affected, and 3 had both mandibular and maxillary periapical lucencies. In these rabbits with grade 2 disease, mandibular third premolar teeth (8/24) or first molar teeth (7/24) were most commonly affected. In contrast, rabbits with grade 5 disease more commonly had periapical lucencies in both the maxilla and mandible; 14 of 20 (70%; 95% CI, 46% to 88%) rabbits had both regions affected, whereas 4 and 2 had only the mandibles or maxilla affected, respectively.

Tooth resorption was detected to some degree in 55 of 100 (55%) rabbits of the present study (Table 1). Frequency and severity of tooth resorption appeared to increase with increasing acquired dental disease grade. All 4 rabbits with grade 4 and 19 of 20 rabbits with grade 5 disease had teeth with severe tooth resorption as noted by several lucent foci and tooth fragmentation (Figure 9). Severe resorption was detected in 6 of 14 (43%; 95% CI, 18% to 71%) and 10 of 60 (17%; 95% CI, 8% to 29%) rabbits assigned grades of 3 and 2, respectively. In rabbits with severe tooth resorption, loss of the apical germinal centers as well as lucent regional areas of resorbed dental tissue were noted. With severe tooth resorption, tooth integrity was lost, leading to abnormal shape changes such as severe malangulation (Figure 10).

Apparent lacrimal canal obstruction or lysis was identified in 17 of 100 (17%) rabbits. These findings were present in rabbits with all dental disease grades (Figure 11).
To the authors’ knowledge, the present study was the first to characterize CT findings for rabbits according to the acquired dental disease classification system described by Harcourt-Brown in addition to previously described CT features of dental disease in this species. There was a high prevalence of dental abnormalities, most of which are not typically evaluated on oral examination or radiographic assessment, identified in the 100 rabbits of the present study. Additional CT findings of abnormalities not previously included in the grading system described by Harcourt-Brown consisted of premolar or molar tooth curvature in a sagittal plane and mandibular canal deformation. However, there was also more subtle evidence of previously described changes such as tooth resorption, periodontal ligament space widening, and apical elongation apparent on CT images. Most of the lesions identified were largely consistent with those previously described by Harcourt-Brown.

Almost all of the dental imaging variables were significantly correlated with each other in the correlation matrix. This suggested that overall deterioration of teeth affected many different CT landmarks concurrently. Additionally, data from the study revealed only fair agreement between the grades assigned to dental quadrant pairs (left vs right and maxillary vs mandibular). This suggested there was some asynchrony in the development of acquired dental disease.

In our study, 36 of 100 (36%) rabbits were known to have undergone dental procedures; however, only 14% had dental procedures performed ≤ 1 month before their CT scans. Age was normally distributed and was the only risk factor associated with increasing acquired dental disease grade and malocclusion stage, which was to be expected if the changes did occur progressively as previously suggested.

History taking and oral examination were important in the diagnostic workup of rabbits with dental disease because many of the described clinical signs can be associated with dental disease. History often revealed pertinent information such as hyporexia or anorexia. Physical and oral examinations of rabbits in the present study often revealed potential clinical signs of dental disease such as ocular discharge, mandibular or maxillary masses, and nasal discharge. Apart from primary clinical signs associated with dental disease, other common clinical signs can be consequences of dental abnormalities. Hyporexia or anorexia is a common early clinical sign in rabbits with dental disease because elongated apices of the mandibular teeth impinge on the inferior alveolar nerve, causing pain and difficulty eating. Hyporexia and anorexia can also be secondary to sharp dental points, which can lacerate the tongue or buccal mucosa. Ocular discharge often develops secondary to maxillary incisor tooth apical elongation or infection, which can impinge on the nasolacrimal duct. Nasal discharge can result when maxillary incisor or premolar tooth (typically first premolar tooth) apices elongate or develop infections that invade the nasal cavity. Facial masses can be detected in the maxillary or mandibular regions as a result of apical elongation and bone remodeling or periapical abscess formation with bone lysis and extension into the soft tissues. Only 29 (29%) of the rabbits in our study had obvious (intraoral) signs of dental disease, and 9 rabbits had no clinical signs of dental disease. However, all rabbits in the study, including those assigned a grade of 1, had at least subtle changes on CT associated with dental disease. The use of CT enables detection of subtle changes in the 3-D structure of a tooth and its surrounding structures and identification of early changes in a rabbit that has no clinical signs of dental disease; this information can guide changes in husbandry and medical management of the pet in
a more timely manner and may potentially slow the progression of dental disease.

Curvature of the premolar and molar teeth in the transverse plane has been reported to occur in a predictable sequence with the mandibular premolar teeth affected first. Curve of the maxillary molar teeth in the transverse plane has not been previously described in the scoring criteria for acquired malocclusion, likely because of difficulty in viewing the shapes and positioning of these teeth on oral examination. We propose that curvature of the maxillary molar teeth should be included in the criteria for stage 3 acquired malocclusion in rabbits. Although difficult to assess without imaging, it is important to remember that tooth crowns in rabbits elongate and curve in a 3-D manner. Curvature of the premolar or molar teeth in a sagittal plane has not been previously emphasized as a finding associated with dental disease in rabbits but was a common finding in rabbits with ≥ grade 2 acquired dental disease in our study sample. The maxillary premolar teeth appeared to curve in a sagittal plane in patients with lower grades of disease. However, mandibular molar tooth curvature in the sagittal plane appeared more frequently in higher grades of disease, and maxillary molar tooth curvature in this plane was rare and found only in rabbits with grade 5 disease. The tips of the premolar and molar tooth crowns were generally curved in a caudal direction with the body of the tooth bowed forward; however, in rabbits with higher dental disease grades, the findings related to curvature were sometimes reversed. Interestingly, neither of the 2 rabbits with grade 1 disease had detectable curvature of these teeth in the sagittal plane. This might have suggested that this feature is more likely to occur in rabbits with acquired dental disease grades ≥ 2, but it is important to consider that the number of rabbits with grade 1 findings was very small.

Almost all rabbits in the present study had signs of apical elongation to various degrees. The mandibular third premolar teeth were possibly the most easily noted teeth with apical elongation and were the only teeth that had this finding in rabbits with low dental disease grades (≤ 2). Compromise of the medial or lingual aspect of the mandibles by these teeth was consistent with typical behavior of these premolar teeth, which commonly penetrate and cause abscess development medially along the mandible. Elongation of the premolar or molar apices was detected at lower grades than expected, with some teeth even penetrating the cortices in rabbits with grade 2 disease. This provided further evidence of the sensitivity of CT imaging and the asynchronous nature of acquired dental disease in rabbits. This also suggested that penetration of the periosteum by elongated apices is not a sufficient criterion for assignment of grade 5. Finally, CT allowed for detection of subtle mandibular premolar or molar tooth apical elongation that would not likely have been clinically detectable on palpation.

Sharp dental points were found in rabbits with all grades of acquired dental disease and were found in 93 (93%) rabbits overall. As expected, dental points were common on the buccal aspects of maxillary premolar and molar teeth, whereas lingual points were more common on mandibular premolar and molar teeth. Interestingly, most rabbits with reverse dental points had high grades of dental disease (ie ≥ grade 3), reinforcing the concept that loss of supporting bone and tooth integrity facilitates improper wear and malpositioning of teeth and leads to abnormal occlusal angles and eventual formation of reverse dental points. We therefore propose that the presence of severe reverse dental points would be a good criterion to include for the classification of acquired dental disease in rabbits, possibly for grades ≥ 3.

Mandibular canal changes do not appear to be a previously described or documented finding in the context of evaluating dental disease in rabbits by use of CT. Changes of the mandibular canal included deformation, loss of distinction, and complete obliteration of the canal. Compression was a feature often seen in rabbits with low grades of disease when simple elongation of tooth apices was present with no substantial secondary changes such as periodontal disease (as evidenced by periodontal ligament space widening, changes in tooth shape, and alveolar expansion). In patients with higher dental disease grades that included development of resorptive lesions and abscesses, the mandibular canal was completely effaced, resulting in poor or no ability to visualize the canal. These results suggested that mandibular canal deformation on CT examination should possibly be added to the criteria for grading of acquired dental disease in rabbits. Changes to the mandibular canal were subjectively less severe in lower grades of disease as evidenced by the ability to still reliably visualize the canal with only changes to the overall shape.

In the present study, more than half the rabbits with malocclusion of the incisor teeth also had premolar or molar tooth clinical crown elongation. These results were similar to those reported for rabbits with dental disease by Riggs et al, who found that 3 of 4 rabbits with malocclusion of the incisor teeth also had clinical crown elongation of premolar and molar teeth. Our data did not show an association between breed and incisor tooth malocclusion, in contrast to the results of previous studies that suggest dwarf rabbit breeds often have incisor tooth malocclusion as a result of mandibular brachygynathism.

The periodontal ligament spaces in 1 rabbit with grade 1 dental disease findings were mildly widened along only the buccal aspect of the maxillary third molar teeth. As described in the study by Riggs et al, dorsal multiplanar reformatted CT images were useful for circumferential evaluation of the periodontal ligament space around individual teeth. Compared with 14 of 15 rabbits in the aforementioned study, our study results revealed periodontal ligament space widening in 76 (76%) of the rabbits evaluated. The authors of the previous study pointed out that cone-beam CT was superior to conventional MDCT for evaluation of the periodontal ligament space be-
cause of better spatial resolution. The differences in sample sizes, populations, and imaging modalities all likely contributed to the discrepancy in the reported frequencies of periodontal ligament space widening between the study by Riggs et al15 and the present study. Widening of periodontal ligament spaces allows pockets to form that can be colonized by bacteria and extend to the tooth apex, increasing the risk of periapical abscesses.5,10 The results of our study indicated that periodontal ligament space and interproximal space widening were correlated with periapical abscess formation.

The contrast resolution of conventional MDCT is an advantage over cone beam CT, as it allows for better distinction of the surrounding soft tissue structures, and enhancement by IV administration of contrast medium can improve distinction of tissue margins; in addition, abscesses often have peripheral contrast enhancement. It is important to know the extent of abscess formation and adjacent tissue involvement in rabbits with dental disease. Because of the nature of abscesses in rabbits, antimicrobial treatment alone is often unsuccessful and surgical treatment is required.10 Our data indicated that concurrent mandibular and maxillary periapical lucencies are more common in rabbits with grade 5 dental disease but can occur in any grade. This was consistent with the originally suggested descriptions7,8,10 of acquired dental disease that indicated periapical lucencies (ie, abscesses) could occur across all grades of disease.

Lacrimal canals were reliably visualized on most CT scans in the absence of pathological changes in the adjacent tissues that could obscure its evaluation. Lacrimal canal changes seemed to occur secondary to diseases of the nasal cavity and paranasal cavities or sinuses (ie, rhinitis and sinusitis), which may or may not have been secondary to maxillary dental disease such as apical elongation of the teeth. Evaluation of the lacrimal canals is important in regard to dental disease because of the close association of these structures with the apices of maxillary incisor teeth.5,8 The lacrimal canal abruptly narrows as it dives medially under the apices of the incisor teeth; therefore, this is a common area of obstruction24 with resulting epiphora. The osseous borders of the nasolacrimal ducts were easily visualized proximally and distally in CT images and could be evaluated for damage or changes secondary to dental lesions; however, definite identification of obstruction requires contrast-enhanced dacryocystography, which was not always available. In addition, the middle portions of the ducts were sometimes difficult to assess owing to close association with the paranasal cavities.

As with all retrospective studies, a limitation in the present study was variability in the documentation of clinical signs and pertinent history as well as a lack of longitudinal data. Missing data can potentially skew results and cause investigators to miss or underestimate meaningful associations. Our study included 23 rabbits that had no breed information available, and some records lacked specific dates for previous dental procedures. In addition, not all CT studies included IV contrast medium administration, which diminished the ability to evaluate soft tissue changes such as abscesses and lymphadenopathy. The rabbits of our study were seen at a first-opinion and referral hospital, which was likely why only 2 rabbits were found to have grade 1 acquired dental disease. Unfortunately, meaningful conclusions could not be drawn for such a small sample size; however, reports of CT studies15,17,22 indicate that normal rabbit skull anatomy and dentition exist. The subset of rabbits with grade 4 disease was also extremely small and similarly limited interpretation of those findings. This was surprising, considering the numbers of rabbits found to have grade 3 or grade 5 disease. On the basis of the small number of rabbits with grade 4 disease, as well as the high degree of overlap between CT-detected changes present in rabbits assigned grades of 4 and 5, we believe it would be warranted to combine these 2 into a single grade reflecting severe acquired dental disease. In the present study, the changes seen in rabbits with overall grade 4 disease such as tooth resorption were often seen in conjunction with changes associated with overall grade 5 disease such as osteomyelitis with periapical abscesses, and these findings were previously used to distinguish between grades of 4 and 5 on evaluation of individual teeth or quadrants with the classical scoring system.8,9 Pathological processes that develop secondary to severe dental disease seem to be intertwined and may be difficult to differentiate. A single combined grade that includes these features could include subclassifications of predominating lesions such as tooth resorption or abscesses when possible.

The CT findings in this study provided additional information from 3-D assessment of the teeth and associated structures that we believe can be used to further improve the classification of acquired dental disease in rabbits. We suggest that a review of the current classification scheme to incorporate these new findings would be beneficial for assignment of individual dental quadrant and overall dental disease grades in rabbits. On the basis of findings in the present study, we recommend the following changes to previously described grading criteria2,8,9 for assessment of acquired dental disease in rabbits (described as PSADD): curvature of maxillary premolar teeth in the sagittal plane and mandibular canal compression as criteria for assignment of grade 2 and curvature of molar teeth in a sagittal plane, reversed occlusal angles, and penetration of the maxillary and mandibular cortices by tooth apices for assigning the highest grade of acquired dental disease (a combination of the previously described grades of 4 and 5). In addition, these results warrant further investigation of associations between the severity of mandibular canal deformation and acquired dental disease grades.
Acknowledgments

Supported by the STAR program of the University of California-Davis School of Veterinary Medicine.

The authors declare that there were no conflicts of interest.

The authors thank Chrisoula A. Toupadakis Skouritakis for technical support related to images.

Footnotes

a. GE LightSpeed 16-slice helical CT scanner, General Electric, Milwaukee, Wis.
b. Efilm, Merge Healthcare, Mississauga, ON, Canada.
c. Isovue 370 (iopamidol 76%), Bracco Imaging Inc, Monroe Township, NJ.
d. Excel 2013, Microsoft Corp, Redmond, Wash.

References


Continued on next page.
Appendix 1

Definitions and descriptions for conditions graded by severity on retrospective evaluation of MDCT images in a study to characterize the CT findings and epidemiological features of dental disease in 100 rabbits.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal findings</th>
<th>Abnormalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incisor tooth apical elongation</td>
<td>Maxillary incisor teeth not extending into the nasal cavity or thinning the ventral part of the incisive bone; mandibular incisor teeth terminate just rostral to the third premolar teeth.</td>
<td>Mild: maxillary incisor teeth thinning the incisive bone cortex; mandibular incisor teeth with germinal centers extending caudally past the third premolar teeth. Moderate to severe: maxillary incisor teeth perforating the incisive bone cortex; mandibular incisor teeth with hard enamel extending past the apices of third premolar teeth.</td>
</tr>
<tr>
<td>Premolar or molar tooth curvature in a lingual or buccal direction (assessed in a transverse plane)</td>
<td>No curvature.</td>
<td>Curvature subjectively assessed as mild, moderate, or severe.</td>
</tr>
<tr>
<td>Premolar or molar tooth curvature in a rostral or caudal direction (assessed in a sagittal plane)</td>
<td>No curvature; normal interproximal spaces.</td>
<td>Mild: maxillary premolar teeth affected. Moderate: mandibular molar teeth affected (curvature into masseteric fossa).</td>
</tr>
<tr>
<td>Premolar or molar tooth apical elongation (best evaluated in a sagittal plane)</td>
<td>No elongation.</td>
<td>Mild: dental enamel points caused by abnormal wear of elongated clinical crowns—normal zigzag pattern of occlusal surface may be preserved. Moderate: steps or waves evident on the occlusal surfaces (ie, loss of normal zigzag pattern). Severe: overgrowth with invasion of the opposing space.</td>
</tr>
<tr>
<td>Premolar or molar tooth apical elongation</td>
<td>No elongation.</td>
<td>Mild: apical elongation with cortical bone thinning. Moderate to severe: cortical bone penetration by tooth apices.</td>
</tr>
<tr>
<td>Mandibular canal deformation (best evaluated in a transverse plane)</td>
<td>Round-to-oval shaped hypoattenuating canal.</td>
<td>Mild: compression or flattening of the canal with loss of normal shape. Moderate: inability to easily trace the canal because of shape deformations. Severe: inability to view the canal or determine its shape.</td>
</tr>
<tr>
<td>Central enamel line changes (best evaluated in a sagittal plane for each cheek tooth)</td>
<td>Readily apparent hyperattenuating central enamel line, compared with findings for adjacent teeth.</td>
<td>Mild: thin line. Moderate: indistinct line. Severe: undetectable line.</td>
</tr>
<tr>
<td>Periodontal ligament space widening (best evaluated in a dorsal plane)</td>
<td>Lamina dura in close contact with reserve crown of tooth. Only a thin lucent rim surrounds the tooth.</td>
<td>Mild: slight, often asymmetric widening of the periodontal ligament space. Moderate: gaps in the alveolus surrounding reserve crowns. Severe: periapical lucencies.</td>
</tr>
<tr>
<td>Loss of lamina dura</td>
<td>A thin line of cortical bone is visible along all sides of the alveolus where the periodontal ligament attaches.</td>
<td>Mild: small lytic holes are evident. Moderate: up to half of the lamina dura is missing. Severe: most or all of the lamina dura is destroyed.</td>
</tr>
<tr>
<td>Cortical lysis due to abscess formation</td>
<td>None.</td>
<td>Mild: punctate lysis. Moderate: 1 cortex lysed (lateral or medial), with changes extending into soft tissue. Severe: 2 cortices lysed, with changes extending into soft tissue.</td>
</tr>
<tr>
<td>Periosteal reaction</td>
<td>None.</td>
<td>Mild: smooth proliferation. Moderate: columnar or palisading reaction. Severe: spiculated or amorphous reaction.</td>
</tr>
<tr>
<td>Tooth resorption</td>
<td>None.</td>
<td>Mild: irregular tooth margins. Moderate: rough or irregular edges with regions of lucency of the teeth. Severe: multiple lucent foci, fragmentation, loss of pulp cavity, and loss of distinction between teeth.</td>
</tr>
<tr>
<td>Soft tissue abscesses</td>
<td>None.</td>
<td>Subjectively assessed as mild, moderate, or severe.</td>
</tr>
<tr>
<td>Nasal disease</td>
<td>None.</td>
<td>Subjectively assessed as mild, moderate, or severe.</td>
</tr>
<tr>
<td>Turbinate loss</td>
<td>None.</td>
<td>Subjectively assessed as mild, moderate, or severe.</td>
</tr>
<tr>
<td>Lacrimal canal</td>
<td>Clear bony canal margins with a lucent center throughout the length of the canal.</td>
<td>Mild: apparent obstruction. Moderate to severe: lysis of bone forming the canal, inability to visibly distinguish and evaluate canal patency.</td>
</tr>
<tr>
<td>Tympanic bulla</td>
<td>Bullae appear symmetric with no fluid, thickening, or lysis.</td>
<td>Mild: fluid-filled bulla. Moderate to severe: osteolytic changes.</td>
</tr>
</tbody>
</table>

Rabbits that underwent MDCT imaging of the skull for any reason from January 1, 2009, to July 31, 2017, were eligible for inclusion in the study.
## Appendix 2

Definitions and descriptions of variables assessed as normal or abnormal on retrospective evaluation of MDCT images in 100 rabbits.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal findings</th>
<th>Abnormalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occlusion of incisor teeth (best evaluated in a sagittal plane)</td>
<td>Mandibular incisor teeth occlude maxillary second incisor teeth and caudal aspects of the maxillary first incisor teeth.</td>
<td>Malocclusion with relative mandibular prognathism and abnormal curvature.</td>
</tr>
<tr>
<td>Dental points</td>
<td>None (buccal and lingual surfaces of the teeth have even wear.)</td>
<td>Presence of sharp dental points on the buccal or lingual surfaces of teeth.</td>
</tr>
<tr>
<td>Apical malangulation</td>
<td>None.</td>
<td>Severe apical curvature or aberrant tortuosity of the tooth apex.</td>
</tr>
<tr>
<td>Interproximal space widening (assessed in a sagittal plane)</td>
<td>None.</td>
<td>Widening of space between the apices of adjacent teeth.</td>
</tr>
<tr>
<td>Periapical lucencies with alveolar expansion</td>
<td>None.</td>
<td>Periapical lucency with expansion of the alveolus laterally and beyond the margins of the germinal expansion centers.</td>
</tr>
<tr>
<td>Calcification of teeth</td>
<td>None.</td>
<td>Subjectively hyperattenuated teeth, compared with normal teeth.</td>
</tr>
<tr>
<td>Tooth fracture</td>
<td>None.</td>
<td>Retained apices or evident fractures.</td>
</tr>
<tr>
<td>Alveolar bullae</td>
<td>Intact structure.</td>
<td>Penetration of bullae by tooth apices.</td>
</tr>
<tr>
<td>Mandibular lymph nodes</td>
<td>Subjectively normal in size.</td>
<td>Enlargement.</td>
</tr>
<tr>
<td>Retropharyngeal lymph nodes</td>
<td>Subjectively normal in size.</td>
<td>Enlargement.</td>
</tr>
</tbody>
</table>