

STANDARD ARTICLE

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Dental disease in alpacas. Part 2: Risk factors associated with diastemata, periodontitis, occlusal pulp exposure, wear abnormalities, and malpositioned teeth

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Abstract

Background: Dental disorders, of which tooth root abscesses are best documented, are highly prevalent in alpacas. Identification of risk factors can be valuable for prevention of dental disorders in this species.

Hypothesis/Objectives: To identify risk factors associated with wear abnormalities, malpositioning, diastemata, periodontal disease (PD), and occlusal pulp exposure at the level of the cheek teeth.

Animals: Two hundred twenty-eight alpacas (*Vicugna pacos*) from 25 farms.

Methods: Cross-sectional study. Dental examinations were performed on sedated animals. Risk factors were determined by clinical examination and interview. Multi-variable logistic regression was used to identify risk factors for wear abnormalities, malpositioned teeth, diastemata, PD, and occlusal pulp exposure.

Results: Mandibular swelling was significantly associated with PD (odds ratio [OR], 11.37; 95% confidence interval [CI], 3.27-48.81; $P < .001$). Nearly 73% of included animals with mandibular swelling concurrently had PD. For every increase in herd size of 1 animal, the risk for PD increased by 2% (95% CI, 1-4%; $P = .01$). The association between severe stages of PD and body condition score (BCS) indicates a painful situation, impairing animal welfare ($P < .001$). For each 1-day increase in interval between pasture cleanings, the odds of finding pulp exposure for a single animal was estimated to increase by 1% (95% CI, 0-2%; $P = .05$).

Conclusion and Clinical Importance: Simple management tools such as measuring BCS, palpating the mandible for bony swellings, removing feces from pasture on a regular basis and decreasing herd size might help identify animals at risk for dental disorders or prevent their development.

KEYWORDS

apical infection, dental abnormalities, dental disease, dental pathology, New World camelids, tooth root abscesses

Abbreviations: BCS, body condition score; CI, confidence interval; OR, odds ratio; PD, periodontal disease.

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1 | INTRODUCTION

Dental disorders are highly prevalent in new world camelids, such as alpacas.^{1,2} The veterinary literature mostly focuses on tooth root abscesses, also termed “apical infections”.^{1,3-5} As seen in other species, apical infections are only part of the problem.^{6,7} They should be considered an advanced stage of dental disease in most cases. When only paying attention to apical infections, a great opportunity to detect and treat underlying preceding conditions is lost. In a field study, oral examination of a large population of alpacas showed high prevalence of a variety of dental disorders such as diastemata (43.1%), wear abnormalities (39.6%), periodontal disease (PD) (32%), malpositioned teeth (19.6%), and occlusal pulp exposure (10.2%).² Clinical signs observed in horses with periodontal disease such as quidding are rarely observed in alpacas, a species that more frequently remains asymptomatic.^{2,8} Decreased food intake and subsequent weight loss are noticed almost exclusively in advanced cases with deep infection.^{4,9} Possible consequences on general health, susceptibility to other disease processes and reproduction results are to be expected. Therefore, dental disorders should be considered a welfare issue in this species. Preventative measures based on well-known risk factors that contribute to the development of dental disorders would be valuable tools in preserving the long-term well-being of new world camelids. However, to date little research has been conducted to investigate possible risk factors for the development and evolution of different dental disorders in alpacas. The abrasive effects of ingesting rough forage with stems on the oral mucosa has been hypothesized to facilitate bacterial colonization, possibly contributing to deep bone infections and tooth root abscesses.¹ To date, no experimental or epidemiological confirmation exists.

Our study aimed to perform risk factor analysis so as to identify predisposing conditions, clinical findings and environmental factors associated with diastemata, wear abnormalities, PD, malpositioned teeth and occlusal pulp exposure at the level of the cheek teeth in alpacas.

2 | MATERIALS AND METHODS

2.1 | Study design, sample size calculation, and selection procedure

A cross-sectional study was conducted on alpaca farms located in Belgium and the Netherlands between June and October 2018. To detect a difference in dental disorders of 20% between the exposed and nonexposed for the risk factor, with 95% confidence and 80% power, 80 observations per factor category were needed. Sample size was set at 200. Participants were selected from the members list of the Alpaca Association Benelux in May 2018 (n = 215 herds) after a positive response to the invitation received. Of 33 interested farms, 25 were conveniently selected, based on traveling distance (95% confident to obtain a prevalence estimate with an accepted error of 10%). The number of animals to be examined at each farm was chosen by

the owner depending on their economic value and the gestational status of presented female animals.

2.2 | Clinical examination and data collection

Dental examinations were performed after deep sedation using a combination of ketamine (5 mg/kg IM, Ketamidol, Richter Pharma, Austria) and medetomidine (30 µg/kg IM, Sedator, Eurovet, Bladel, Belgium) or dexmedetomidine (15 µg/kg IM, Dexdomitor, Orion Corporation Orion Pharma, Espoo, Finland). The oral cavity was thoroughly irrigated to evacuate food particles. A miniature pony speculum was used, combined with a dental speculum light. A custom-made dental chart was completed for each animal after examination of teeth and surrounding soft tissues using a dental mirror or a rigid portable endoscope (Karl Storz, Tuttlingen, Germany). Specific dental disorders to be investigated at the level of the cheek teeth included the presence of wear abnormalities, malpositioned teeth, diastemata, PD and defects in the secondary dentin indicating possible pulp exposure.

Predetermined factors (Table 1) were recorded during a personal interview (K. Proost). These included age and sex, food management (n = 4), herd characteristics (n = 2), general farm management (n = 4), and clinical signs (n = 4). Additionally, body condition score (BCS) was determined by the same person using a preset 5-point scoring system.¹⁰ External palpation of the maxilla and mandible also was performed to detect bony enlargements, fistulous tracts, or both.

TABLE 1 Questionnaire provided to the alpaca owner to collect information concerning possible associated factors on an animal level (all questions were yes versus no questions unless otherwise specified between brackets)

Subject	Description
Age	Age at the time of the farm visit (birth date)
Sex	Female/male/male castrated
Gestation	Only for ♀. Gestational status; duration of gestation (days)
Cria	Only for ♀. Cria accompanying dam; age of the cria (days)
Clinical signs (owner)	Mandibular swelling, appetite decrease; quidding; salivation; weight loss
Feed management	Quality of hay (hard, soft, mixture); feeding of alfalfa hay; feeding of beet pulp; feeding of grass mix
Herd characteristics	Herd size (number of animals), stocking density (animals/surface unit [hectare])
General farm management	Stable housing during a specific time of the year; stable housing during the night; pasture cleaning by the owner (regardless of the frequency); frequency of pasture cleaning (interval between 2 performances)

2.3 | Statistical analysis

The unit of analysis was the individual animal. Five age categories were constructed: Group A (0-3 years), Group B (3.1-6 years), Group C (6.1-9 years), Group D (9.1-12 years), and Group E (12.1-17 years). Furthermore, animals were divided into 4 BCS categories: category 1 (0-1), category 2 (1.5-2), category 3 (2.5-3), and category 4 (3.5-5). Statistical analysis was limited to selected dental disorders with >20 observations. Diastemata, PD (and also interproximal gingival retraction), occlusal pulp defects, wear abnormalities, and malpositioned teeth were used as variables of interest. Six multivariable mixed effects logistic regression models (glmer) with herd as a random factor to account for clustering were built. First, the association of each factor with outcome was tested univariably. Factors with $P < .20$ were retained for the multivariable model. Associations between significant predictors were tested, and only the most significant variable was maintained in the model. The multivariable model was built backward in a stepwise fashion, gradually excluding nonsignificant variables. Biologically relevant interactions between significant main effects were tested. The deviance residuals were plotted against the predicted probabilities to inspect for model adequacy. Furthermore, a half-normal probability plot was constructed to inspect for model adequacy and potential outliers. A plot of the delta deviance statistics was used to check for evidence of potential influential observations. Model fit was determined using the McFadden R^2 . Sensitivity, specificity, accuracy, and associated confidence intervals (CI) were calculated from predictions based on all constructed models. The attributable risk was calculated for biologically relevant categorical risk factors. Significance was set at $P < .05$. The program R V3.5.2 (R foundation for statistical analysis) was used for statistical analyses.

3 | RESULTS

3.1 | Herd and animals

Two hundred twenty-eight alpacas were included in the study, with a mean number of $9 \pm SD 7$ (range, 1-28) animals examined at each farm. The mean age of the alpacas included in the study was 5.60 ± 3.17 years (range, 1-17 years). The BCS was determined for all included animals and averaged 2.5 ± 1 , ranging from 0.5 to 4.5. Seventy-seven percent (175/228) of animals had a BCS between 1.5 and 3. The herd size of included farms ranged from 4 to 80 animals with a mean of 33 ± 22 animals. The stocking density varied from 2 to 77 animals housed per hectare, with a mean of 28 ± 20 animals. Of the animals, 22.8% (52/228) were housed in the stable without pasture access during a specific time of the year. Furthermore, 14.5% (33/228) were kept indoors overnight. Removal of feces from the pasture was performed on 60% of the farms, involving 57.5% (131/228) of the alpacas studied. The interval between 2 pasture cleanings in these cases was 180 days maximum, with a mean of 17 ± 42 days.

All animals were fed hay ad libitum. The owners provided soft hay in 55.3% (126/228) of cases. Only 7.9% (18/228) of animals were

fed hay with stems on a regular basis. Nearly 37% (84/228) of animals were reported to receive a variety of hay types. Twenty-five percent (58/228) were fed alfalfa hay or pellets on a regular basis. Furthermore, beet pulp and grass mix also were administered to 69.7% (159/228) and 48.7% (111/228) of the animals, respectively.

Overall, alpaca owners were aware of dental-related clinical signs in 6.6% (15/228) of their animals. These signs included weight loss in 13/228 (5.7%) animals as well as mandibular swelling (9/228, 3.9%), quidding (4/228, 1.8%), decreased appetite (3/228, 1.3%), and salivation (1/228, 0.4%). Nevertheless, in 9.6% (22/228) of the animals, mandibular swelling could be detected on palpation by the primary investigators during the farm visit. Only a single animal had external mandibular fistulation associated with a localized mandibular swelling. Maxillary swelling, external fistulation, or nasal discharge was not detected in any animal.

3.2 | Prevalence of included dental disorders

The prevalence of diastemata, wear abnormalities, PD, malpositioned teeth, and occlusal pulp exposure at the level of the cheek teeth in the studied alpaca population was 43.1% (97/228), 39.6% (89/228), 32.0% (73/228), 19.3% (44/228), and 10.1% (23/228), respectively. First, a univariable analysis was constructed for all included dental disorders the full results of which can be found in the supporting information. Only factors with $P < .20$ have been included in the tables. Results of the multivariable analysis are reported hereafter specifically for diastemata, PD, occlusal pulp exposure, wear abnormalities, and malpositioned teeth.

3.3 | Diastemata and associated risk factors

Univariable analysis showed statistically significant associations between diastemata and age category ($P < .001$), BCS category ($P < .001$), clinical signs in general ($P < .001$), mandibular swelling ($P = .01$), feeding of alfalfa ($P = .05$), and feeding of grass mix ($P = .01$). As already identified in another study, other dental disorders comprising malpositioned teeth ($P = .04$), PD ($P < .001$), tooth fractures ($P = .01$), and defects in the secondary dentin indicative of pulp exposure ($P < .001$) were univariably significantly associated with the presence of diastemata (Table S1).² After construction of the multivariable regression model including risk factors and other associated dental disorders, age category, feeding of grass mix and presence of PD remained significantly associated with the presence of diastemata (Table 2). Animals in higher age groups showed higher odds of presenting with diastemata. Furthermore, alpacas that were fed grass mix on a regular basis and those diagnosed with PD had 2.1 (95% CI, 1.1-4.3; $P = .03$) and 10.5 (95% CI, 5.2-22.5; $P < .001$) higher odds of having a diastema, respectively. Accuracy, sensitivity, and specificity of the constructed model was 77.8% (95% CI, 71.8%-83.0%), 70.1% (95% CI, 61.0%-79.2%), and 83.6% (95% CI, 77.2%-90.0%), respectively.

3.4 | Wear abnormalities and associated risk factors

Wear abnormalities were the second most commonly detected dental disorders in our study including worn teeth (57/228, 25.0%), focal overgrowths (19/228, 8.3%), and single accentuated transverse ridges (24/228, 10.5%). Other wear abnormalities such as shear mouth, wave mouth, step mouth, and enamel overgrowths only were seen occasionally. Results of the univariable analysis are presented in Table S2. Only age category was withheld as a statistically relevant risk factor after multivariable analysis (Table 3). Animals in higher age categories had higher odds of presenting with wear abnormalities. Accuracy, sensitivity, and specificity of the constructed model were 72.9% (95% CI, 66.6%-78.6%), 49.4% (95% CI, 39.1%-59.8%), and 88.2% (95%CI, 82.8%-93.7%), respectively.

3.5 | Periodontal disease and associated risk factors

Within the group of animals diagnosed with PD at the level of the cheek teeth, the majority of animals exhibited interproximal gingival retraction (64/75; 85.3%). Other presentations of PD included mild gingivitis (14/75; 18.7%), drainage of exudate (12/75; 16%), and increased tooth mobility (14/75; 18.7%). Results of the univariable analysis for the different included factors are presented in Table S3. Multivariable analysis identified a statistically

significant association between PD and herd size, mandibular swelling, and presence of diastemata (Table 4). Animals with mandibular swelling or diastema had 11.4 (95% CI, 3.3-48.8; $P < .001$) and 12.6 (95% CI, 6.2-27.4; $P < .001$) higher odds of concurrently having PD, respectively. In animals diagnosed with diastemata, 82.4% of PD was attributable to the presence of these diastemata (95% CI, 70.4%-89.6%). For each increase in herd size of 1 unit, the odds of having PD for a single animal was estimated to increase by 2% (95% CI, 1%-4%; $P = .003$). The sensitivity, specificity, and accuracy of the statistical model was 65.3% (95% CI, 54.6%-76.1%), 86.3% (95% CI, 80.8%-91.7%), and 79.3% (95% CI, 73.6%-84.4%), respectively.

Given the high prevalence of interproximal gingival retraction within the PD category, a specific logistic regression model was constructed for this condition. Univariablely, 8 general risk factors were associated with interproximal gingival retraction (Table S4). In the multivariable model, the same factors as for PD in general were withheld (Table 5). Furthermore, in animals diagnosed with diastemata, 82.9% of interproximal gingival retraction could be attributed to the presence of diastemata (95% CI, 70.0%-90.3%). Additionally, the BCS category also was associated with interproximal gingival retraction. Animals in a higher BCS category had lower odds of presenting with interproximal gingival retraction. Accuracy of the constructed multivariable model was 84.1% (95% CI, 78.7%-88.6%). In comparison to the general PD model, a lower sensitivity (56.3%; 95% CI, 44.1%-68.4%) and higher specificity (95.5%; 95% CI, 91.8%-98.4%) was calculated.

Diastemata					
Variable	Category	Animals (n)	Disease (%)	OR (95% CI)	P value
Age category	0-3 years	46	6.5	Referent	
	3-6 years	103	16.5	1.07 (0.43-2.76)	.89
	6-9 years	41	34.1	2.14 (0.75-6.27)	.16
	9-12 y	22	68.2	10.66 (2.45-59.04)	.003
	12-17 y	13	76.9	10.06 (1.81-81.24)	.01
Periodontal disease	No	153	9.2	Referent	
	Yes	75	60.0	10.52 (5.20-22.45)	<.001
Grass mix	No	117	24.8	Referent	
	Yes	111	27.0	2.11 (1.06-4.29)	.03

TABLE 2 Final multivariable model showing factors associated with the presence of diastemata in the study population consisting of 228 alpacas

Wear abnormalities					
Variable	Category	Animals (n)	Disease (%)	OR (95% CI)	P value
Age category	0-3 y	46	26.1	Referent	
	3-6 y	103	26.2	.84 (.35-2.05)	.71
	6-9 y	41	51.2	3.38 (1.29-9.51)	.02
	9-12 y	22	86.4	24.85 (6.02-145.34)	<.001
	12-17 y	13	76.9	11.69 (2.61-71.11)	.003

TABLE 3 Final multivariable model showing the sole risk factor associated with the presence of wear abnormalities at the level of the cheek teeth in the studied alpaca population consisting of 228 animals

3.6 | Malpositioned teeth and associated risk factors

In the analysis, no differentiation was made in severity or angle of malpositioning. After performing a univariable analysis, 6 remaining factors were significantly associated with the presence of malpositioned teeth: weight loss ($P = .05$), stable housing during the night ($P = .01$), feeding of grass mix ($P = .05$), presence of persisting deciduous teeth ($P = .03$), presence of diastemata ($P = .04$), and presence of PD ($P = .01$; Table S5). An association was detected between 2 significant predictors, the presence of persisting deciduous teeth and the presence of PD. The presence of persisting deciduous teeth was significantly correlated with the presence of malpositioned teeth, but the presence of PD was more significantly linked to the presence of malpositioned teeth. Persisting deciduous teeth therefore were excluded during further model building. The final multivariable model included 3 significant associated factors (Table 6). Animals that were given access to pasture during the night had lower odds (OR [95% CI],

0.3 [0.1-0.7]; $P = .004$) of having malpositioned teeth. Also, animals that were fed grass mix (95% CI, 1.1-4.9; $P = .02$) or that had PD (95% CI, 1.2-4.6; $P = .02$) had 2.3 higher odds of having malpositioned teeth. In animals with PD at the level of the cheek teeth, 52.9% of displaced teeth were attributable to the presence of PD (95% CI, 20.7%-72.0%). A low sensitivity was calculated for our constructed multivariable model (6.8%; 95% CI, -0.6% to 14.3%) whereas a high specificity was obtained (99.5%; 95%CI, 98.4%-100.5%). Accurate predictions could be made based on the constructed multivariable model in 81.6% of cases (95% CI, 75.9%-86.4%).

3.7 | Occlusal pulpar exposure and associated risk factors

Despite the relatively low number of observations, a multivariable logistic regression model was constructed for occlusal pulpar exposure to determine associated factors, given its clinical importance. Results

TABLE 4 Final multivariable model showing the specific factors associated with the presence of periodontal disease

Periodontal disease					
Variable	Category	Animals (n)	Disease (%)	OR (95% CI)	P value
Mandibular swelling	No	206	27.2	Referent	
	Yes	22	81.8	11.37 (3.27-48.81)	<.001
Diastema	No	131	11.5	Referent	
	Yes	97	61.9	12.63 (6.22-27.42)	<.001
Herd size	Cont.	228		1.02 (1.01-1.04)	.001

TABLE 5 Final multivariable model showing the specific factors associated with interproximal gum retraction

Interproximal gingival retraction					
Variable	Category	Animals (n)	Disease (%)	OR (95% CI)	P value
BCS category	0-1	19	68.4	Referent	
	1.25-2	72	37.5	.34 (.08-1.23)	.11
	2.25-3	103	19.4	.25 (.06-.89)	.04
	3.25-5	33	12.1	.10 (.02-.52)	.01
Mandibular swelling	No	206	23.3	Referent	
	Yes	22	72.7	5.88 (1.79-21.99)	.01
Diastema	No	131	9.2	Referent	
	Yes	97	53.6	10.21 (4.62-24.53)	<.001
Herd size	Cont.	228		1.03 (1.02-1.05)	<.001

TABLE 6 Final multivariable model showing the specific factors associated with the presence of malpositioned teeth at the level of the cheek teeth

Malpositioned teeth					
Variable	Category	Animals (n)	Disease (%)	OR (95% CI)	P value
Periodontal disease	No	153	14.4	Referent	
	Yes	75	29.3	2.30 (1.15-4.63)	.02
Night pasture	No	33	24.2	Referent	
	Yes	195	18.5	.28 (.12-.69)	.004
Grass mix	No	117	17.9	Referent	
	Yes	111	20.7	2.31 (1.13-4.85)	.02

TABLE 7 Final multivariable model showing factors associated with the presence of occlusal pulp exposure in the study population consisting of 228 animals

Occlusal pulp exposure					
Variable	Category	Animals (n)	Disease (%)	OR (95% CI)	P value
Clinical signs	No	199	6.5	Referent	
	Yes	29	37.9	5.53 (1.98-15.57)	.001
Diastema	No	131	2.3	Referent	
	Yes	97	21.6	8.58 (2.69-38.29)	.001
Frequency pasture cleaning	cont.	228		1.01 (1.00-1.02)	.05

Note: Clinical signs as perceived by the owner. This can include mandibular swelling, appetite decrease, quidding, salivation, and/or weight loss.

of the univariable logistic regression analysis are presented in Table S4. Multivariable logistic regression analysis showed associations between pulp exposure and the observation of clinical signs, frequency of pasture cleaning, and presence of diastemata (Table 7). Animals showing ≥ 1 of the dental-related clinical signs had 5.5 times (95% CI, 2.0-15.6; $P = .001$) higher odds of being diagnosed with occlusal pulp exposure during oral examination. Animals with ≥ 1 diastemata had 8.6 (95% CI, 2.7-38.3; $P = .001$) higher odds of suffering from occlusal pulp exposure. In animals with diastemata, 89.4% of detected occlusal pulp exposure was attributable to the presence of these diastemata (95% CI, 65.5%-96.8%). For each 1-day increase in interval between 2 pasture cleanings, the odds of showing occlusal pulp exposure at the level of 1 of the cheek teeth for a single animal was estimated to increase by 1% (95% CI, 0%-2%; $P = .05$). A low sensitivity (8.3%; 95% CI, -2.7 to 19.4%) but a high specificity was determined for this model (99.5%; 95% CI, 98.6%-100.5%). Overall, the accuracy of the constructed multivariable model was 90.0% (95% CI, 85.3%-93.5%).

4 | DISCUSSION

Our aim was to identify possible risk factors for highly prevalent dental disorders such as diastemata, PD, occlusal pulp exposure, wear abnormalities, and malpositioned teeth diagnosed in a large population of alpacas during a cross-sectional field study.² The results may contribute to a better understanding of the pathogenesis of dental disease in alpacas and to the development of preventative guidelines for owners. Despite the fact that the number of identified risk factors was rather small, their relative contribution to the observed diseases was substantially large.

Diastemata were found to be the most prevalent dental abnormality in our studied alpaca population. Diastemata and wear abnormalities were significantly more prevalent in higher age categories, illustrating their developmental nature similar to what is known in horses and donkeys.^{2,6,11-13} The clinical importance of the presence of PD was illustrated by lower BCS significantly associated with the presence of interproximal gum retraction. Weight loss reflects impaired food intake and decreased masticatory efficiency related to oral discomfort.^{9,14} Dental disorders in dairy goats have been reported to cause weight loss but also have been associated with a significant drop in milk production.¹⁵ In dairy cows, a decrease in BCS has been associated with lower

likelihood of successful pregnancy, but this relationship has not yet been studied in new world camelids.¹⁶ In this animal species, notorious for its ability to hide clinical signs related to dental disease, recording BCS on a regular basis can be a simple means of monitoring welfare and might encourage alpaca owners to seek specialist dental care.

No specific clinical signs could be attributed to a specific dental disorder. However, when clinical signs of oral discomfort were noted, occlusal pulp exposure was diagnosed more frequently. As already described in horses, normal and healthy pulp chambers never should become occlusally exposed.¹⁷ Occlusal pulpar exposure suggests a history of severe pulp disease of longer duration.¹⁸ In only 6.6% of animals did the owner suspect the presence of dental disease whereas 9.6% of animals had external swelling of the mandible indicative of deeper infections and >30% of animals were diagnosed with severe dental problems consisting of PD, occlusal pulpar exposure, or both. In 8/22 (36.4%) of animals with mandibular swelling, occlusal pulpar exposure was detected during oral examination. Mandibular swelling was strongly associated with the presence of PD, which reflects the advanced stage of the disease most likely inducing deep infection with associated bone remodeling responsible for the bony swelling. Routine palpation of the mandibular arcades on a regular basis therefore is recommended to identify those animals at risk for PD. This also illustrates the need for owner education regarding monitoring their animals and, as in horses, shows that alpacas could benefit from preventative dental examinations to diagnose dental disorders in earlier stages of their development. We believe a minimum age of 3 years to start dental examinations would be of value in alpacas. The frequency of additional dental examinations should be dependent on the findings in the first oral examination. Yearly follow-up of at-risk cases is beneficial in our opinion despite the labor-intensive nature of the examination and the requirement for deep sedation. If no abnormalities are detected during the first examination, owners can be instructed to evaluate regularly for mandibular swellings or changes in BCS while postponing additional oral examinations. However, the risk of diagnosing dental disorders only at an advanced stage should be taken into account when allowing large intervals to occur between examinations.

As already reported in horses,^{14,19,20} a strong association between diastemata and PD was found in our study. In animals in which diastemata were recorded, the majority of PD could be attributed to the presence of these diastemata. This same observation was made for diastemata and occlusal pulpar exposure. Malpositioned teeth also were

strongly associated with PD and can be both the cause and result of periodontal tissue destruction. Food impaction in the interproximal space initiates a cascade of inflammatory reactions causing mild gingivitis to evolve into more severe PD stages and even apical infection in suitable circumstances as already recognized in human and equine dentistry.⁸ Preventative measures for the development of PD should consist mainly of strategies to decrease the accumulation of food particles at the level of the gingival margin. Periodontal disease in horses is a frustrating condition, which is difficult to treat and often requires life-long follow-up. Conservative treatment strategies in this species often combine debridement of periodontal pockets with filling or widening of causal diastemata and correcting any associated wear abnormality such as accentuated transverse ridges opposing a diastema.²¹⁻²³ In animals that have increased tooth mobility or severe tooth displacement, tooth extraction is preferred. We have performed diastema debridement and corrective odontoplasty, as well as tooth extraction in several alpacas with PD, with variable success. Widening of diastemata does not seem practically applicable in alpacas given the small size of their teeth and the likelihood of iatrogenically opening pulp canals adjacent to the interproximal space. Further research is warranted to optimize treatment options for these animals.

The quality of administered roughage is speculated to play a role in the development of advanced dental pathology such as apical infections in alpacas. Rough forages with stems facilitate colonization of the oral mucosa in general and the periodontal space in particular by its abrasive effects allowing the entrance of commensal bacteria and food particles into the periodontal space.¹ However, no significant effect of type of hay on the prevalence of any of the investigated dental disorders and, more specifically PD, could be detected in our study. Nevertheless, this finding should not definitively exclude hay quality as a risk factor given the absence of objective criteria to evaluate hay quality in our study. The latter was subjectively determined by the owner and the information retrieved from our questionnaire. Our study also showed an association between feeding grass mix and the presence of diastemata and malpositioned teeth. Confounding with another unidentified variable cannot be excluded. Owners also might have been biased to feed grass mix in animals struggling to maintain adequate BCS. A prospective study on the development of dental disease using specific criteria for roughage quality would be a more precise tool to investigate this relationship.

An interesting effect of farm management was the impact of herd size. Animals that were part of a larger herd were more at risk to show PD. One possible explanation for this phenomenon could be the higher stress level in larger alpaca herds, because new world camelids are prone to develop stress under a variety of circumstances. In human dentistry, stress and anxiety are believed to play a role in the complex pathogenesis of PD. To date, they have been identified in observational studies as potential risk factors.²⁴ Although, the pathogenesis of PD at the level of the cheek teeth as detected in species with hypsodont teeth differs from the plaque-induced periodontitis found in brachydont species, such as humans,⁸ both share the resultant destructive inflammatory response. High stress levels can impair the immune response elicited to periodontal colonization of bacteria. More specifically, individual variation in immune response can destroy invading bacteria, but also surrounding periodontal

structures.^{25,26} Evidence exists of a substantial genetic basis for the development of PD in men. In alpacas, no studies have yet been conducted to investigate genetic impact on the prevalence of PD.

The frequency of pasture cleaning was identified as an additional risk factor for development of dental disease, more specifically the presence of occlusal pulp exposure. The latter was less prevalent in animals on farms with a smaller interval between pasture cleanings. Pasture cleaning was carried out on 15 of 25 farms. Our findings are similar to the lower reported prevalence of mandibular osteomyelitis in Bennett's wallabys (*Macropus rufogriseus rufogriseus*) when rigorous removal of feces was performed on their premises. The decrease in exposure to pathogenic bacteria in this species proved to be far more successful than attempting to treat deep bone infections. Other husbandry changes with a positive influence on oral health in wallabys include decreasing stocking densities, paddock resting and rotation, and avoiding using processed foods and forage with sharp awns.²⁷ Remarkably, no significant effect of stocking densities on the prevalence of included dental disorders could be detected in our current alpaca study. Nevertheless, the frequency of pasture cleaning in alpacas should be considered alongside these other husbandry changes because we do not expect these to be completely independent of each other. Presumably, motivated owners would be expected to keep their pastures free of feces. Further research is warranted to study the specific individual value of the investigated risk factors to the development of studied dental disorders.

Selection bias cannot be ruled out, because only members of the Alpaca Association Benelux were contacted to participate. These alpaca owners are well informed about the different aspects of alpaca farming through their association, which might have biased our study population toward animals with higher quality caretaking. However, the relatively low number of animals suspected by the owners of having dental problems compared to the number of animals diagnosed with dental disease clearly illustrates the need for improvement in health management. On farm, the authors were not able to randomly choose their research subjects because some owners were reluctant to have very valuable animals or some pregnant females sedated for closer examination. This factor might have influenced the results.

In conclusion, we identified several risk factors for specific dental disorders in alpacas. In animals diagnosed with diastemata, most PD cases were attributable to the presence of these diastemata. Older animals with lower BCS or exhibiting clinical signs noticeable by the owner showed higher odds of presenting with dental disorders during oral examination. Simple management tools such as measuring BCS and palpating the mandible for the presence of bony swellings can increase the time and attention provided for the individual animal and can aid in identifying animals at risk for the presence of dental disorders. Furthermore, removing feces from pasture on a regular basis might have a positive effect on preventing development of dental disorders. Owner education is of primary importance to improve the welfare of these animals.

ACKNOWLEDGMENTS

The authors thank all volunteering owners of participating alpaca farms. The authors also thank Ms Ann-Sophie Platteeuw for her aid with the data collection on several alpaca farms.

CONFLICT OF INTEREST DECLARATION

A call for volunteering alpaca farms was spread through the Alpaca Association Benelux (AAB). One of the coauthors (T. Flahou) is member of the AAB and participated in this study with animals present at his alpaca farm. The AAB played no role in the final selection of participating farms nor in the collection, analysis, and interpretation of data, nor in the decision to submit the manuscript for publication. B. Pardon acted as an unpaid consultant for the AAB. None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the article.

OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Authors declare no IACUC or other approval was needed.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Proost K, Pardon B, Pollaris E, Flahou T, Vlamincck L. Dental disease in alpacas. Part 2: Risk factors associated with diastemata, periodontitis, occlusal pulp exposure, wear abnormalities, and malpositioned teeth. *J Vet Intern Med.* 2020;34:1039–1046. <https://doi.org/10.1111/jvim.15740>