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Contribution of abdominal radiography to the diagnosis of enterolithiasis in horses

Contribuição da radiografia abdominal para o diagnóstico de enterolitíase em equinos

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Highlights

Obesity interfered with the quality of equine abdominal radiographic images.
The location and number of enteroliths did not hinder the radiographic diagnosis.
Abdominal distension can lead to false-negative radiographic results.

Abstract

Enteroliths are mineralized concretions found in the large intestines of horses that can cause impaction colic by impeding normal enteric flow, typically at points of reduced intestinal diameter. They are highly prevalent and significantly detrimental in the equestrian environment. A presumptive diagnosis is based on the history and clinical signs, while a definitive diagnosis is possible only through exploratory laparotomy or abdominal radiography. This study aimed to determine the clinical applicability of established parameters for performing radiographic diagnoses in cases of equine enterolithiasis and to compare these findings between a group with enterolithiasis and a control group. The medical records of 92 horses treated for colic syndrome between June 2022 and October 2023 were retrospectively evaluated. This included 32 animals presenting with clinical signs of impaction colic originating from the large intestine or with a history of recurrent abdominal pain, all of whom underwent abdominal

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radiography and for whom definitive diagnosis was achieved through laparotomy. The study groups comprised 12 control animals and 20 in the enterolithiasis group. The study investigated the influence of the size, number, and location of enteroliths on radiographic detection, in addition to identifying factors that hindered the performance of the diagnostic technique and its correlation with surgical findings. During the study, 85.5% of the animals in the enterolithiasis group (17/20) were pre-surgically diagnosed with enterolith through abdominal radiography, while three animals presented false-negative results and were diagnosed through exploratory laparotomy. The number of concretions showed significant statistical relevance. The main factors that interfered with the radiographic diagnosis were abdominal distension, weight, and body condition score. These findings indicate that this diagnostic method, regardless of the obstructed segment and the number of enteroliths, is easier to apply when more than one concretion is present. The study demonstrated that abdominal digital radiography is an important auxiliary method for pre-surgical diagnosis in cases of equine enterolithiasis. The feasibility of this diagnostic method was found not to depend on the obstructed segment or the number of enteroliths, which are more easily observed in animals with more than one concretion. However, caution is advised when interpreting images of obese horses or those with abdominal distension due to gas, as these conditions have led to false-negative diagnoses. This research highlights the importance of abdominal radiography in managing enterolith cases for timely therapeutic intervention and improved prognosis.
Key words: Horse. Imaging diagnosis. Impaction colic. Multiple correspondence analysis.

Resumo

OEnterólitos são concreções mineralizadas encontradas no intestino grosso dos equinos, que podem causar cólicas obstrutivas ao impedir o fluxo entérico normal, geralmente em pontos de redução do diâmetro intestinal. Apresenta alta incidência e causa grandes prejuízos no meio equestre. O diagnóstico presuntivo é realizado com base no histórico e sinais clínicos enquanto o diagnóstico definitivo só é possível na celiotomia exploratória ou radiografia abdominal. O presente trabalho teve como objetivo verificar a aplicabilidade clínica de parâmetros já estabelecidos para realização de diagnóstico radiográfico em casos de enterolitíase equina, e comparar esses achados entre um grupo com enterolitíase e um grupo controle. A partir dos prontuários de 92 equinos atendidos com síndrome cólica em um período que compreendeu junho de 2022 a outubro de 2023, os registros foram avaliados de maneira retrospectiva e incluíram 32 animais, que foram atendidos com sinais clínicos de cólica obstrutiva advinda do intestino grosso ou com histórico de dor abdominal recorrente, que realizaram exame de radiografia abdominal e que foi possível obter o diagnóstico definitivo por meio de celiotomia. Doze animais compuseram o grupo controle e vinte o grupo enterolitíase. Foi verificada a influência do tamanho, número e localização do enterólito na detecção radiográfica, além de identificação de fatores que dificultaram a realização da técnica diagnóstica e (correlacionados aos achados cirúrgicos. Durante o estudo, 85,5% dos animais do grupo enterolitíase (17/20) obtiveram o diagnóstico pré-cirurgico de enterólito por meio da radiografia abdominal enquanto três animais apresentaram falso-negativo e obtiveram o diagnóstico na celiotomia exploratória. O número de concreções apresentou relevância estatística significativa. Os principais fatores que interferiram no diagnóstico radiográfico foram a distensão abdominal, peso e o escore de condição corporal, indicando essa forma diagnóstica, independente do segmento obstruído e do número de enterólitos, sendo mais fácil a identificação

quando existir mais de uma concreção. O presente estudo evidenciou que a radiografia digital abdominal é um importante método auxiliar de diagnóstico pré-cirúrgico nos casos de enterolitíase equina, sendo verificado a possibilidade dessa forma diagnóstica independente do segmento obstruído e do número de enterólitos, apresentando mais facilidade de observação nos animais com mais de uma concreção. No entanto, ressalta-se a necessidade de cautela na interpretação de imagens de equinos obesos e com presença de distensão abdominal por gás, situações em que ocorreram diagnósticos falso negativos. O presente estudo elucidou a importância da radiografia abdominal no atendimento de casos de enterólito para uma intervenção terapêutica precoce e um melhor prognóstico.
Palavras-chave: Análise de correspondência múltipla. Cavalo. Cólica obstrutiva. Diagnóstico por imagem.

Introduction

Enterolithiasis in horses is endemic in certain areas, such as the southern region of Brazil. Enteroliths are intestinal stones formed from minerals like struvite, magnesium, and ammonia (Southwood, 2019), along with other substances including sodium, potassium, phosphorus, calcium, and sulfur (Hassel et al., 2001). These stones can lead to impaction colic, characterized by signs of intestinal hypomotility, reduced or absent defecation, the presence of mucus in the feces, abdominal distension, and pain (Pierce, 2009).

Accurately diagnosing the etiologies causing abdominal pain in horses poses a significant challenge. Information from a well-conducted anamnesis as well as a thorough clinical examination are of great value. Additionally, complementary techniques such as imaging tests and clinical pathology contribute significantly, both in field care and at reference centers. To effectively utilize these auxiliary methods, veterinarians must be familiar with the indications and limitations of each technique (Cook & Hassel, 2014).

Radiography is widely employed in diagnosing diseases of the equine locomotor system and dentistry. This examination can also prove invaluable for diagnosing abdominal conditions. However, radiographing the abdomen of an adult horse requires high-exposure equipment, which is either stationary or large, necessitating transport of the patient to the facility. Abdominal X-rays can swiftly diagnose obstructive conditions of the large intestine, such as enterolithiasis, thereby facilitating early surgical intervention (Keppie et al., 2008), and thus serving as an important diagnostic tool. According to Kelleher et al. (2014), radiography exhibits higher sensitivity and specificity for diagnosing enteroliths in the large colon, but shows lower sensitivity for small colon enteroliths; the effectiveness of the technique is compromised by the presence of abdominal gas, often associated with pathology at this site.

The objective of this study is to examine the clinical applicability of established parameters for performing radiographic diagnoses in cases of equine enterolithiasis and to compare these findings between a group with enterolithiasis and a control group.

Material and Methods

This study utilized medical records from 92 horses treated for colic syndrome or with a history of recurrent abdominal pain from June 2022 to October 2023 at the Guadalupe Veterinary Clinic in Rio Grande do Sul, Brazil.

The inclusion criteria specified horses exhibiting clinical signs of impaction colic originating from the large intestine, such as: recurrent signs of abdominal pain (manifested by digging the ground, rolling, and looking at the flank); reduced or absent defecation; abdominal distension; and intestinal hypomotility. Alternatively, horses with a history of recurrent abdominal pain, which did not manifest clinical signs at the time of treatment, were included if they underwent abdominal radiography and a definitive diagnosis was possible through laparotomy.

Animals

1. *Control group* – Control Group: Included horses that displayed clinical signs of abdominal discomfort linked to the large intestine but had abdominal radiographs showing no mineral opacity suggestive of enterolithiasis. All animals in this group underwent median laparotomy due to non-responsiveness to clinical treatment involving fluid therapy, prokinetic medications, laxatives, and analgesia, and were diagnosed with conditions other than enterolithiasis affecting the large intestine.

2. *Enterolithiasis group* – This group included horses displaying clinical signs of abdominal discomfort linked to the large intestine similar to those in the control group, or with a history suggestive of enterolithiasis. These horses had undergone abdominal radiography (with or without an image suggestive of enterolithiasis) and were surgically diagnosed with enterolithiasis.

Radiography

Radiographic images were obtained using a MAG DYNAMIC C 500 mA/150 kV X-ray machine and were evaluated by three veterinarians experienced in the field. The imaged abdominal regions included the cranial ventral and dorsal abdomen, and the caudal ventral and dorsal abdomen. It is important to note that the variable 'number of projections' may also relate to the limited size of the imaging plate, necessitating a larger scan in less apparent cases such as horses without distension, clinical obstruction in the right dorsal colon, and to determine the presence of additional concretions.

Animals were initially imaged in left lateral-lateral projections. If no mineral opacity suggestive of enterolithiasis was observed, dorsoventral projections were performed on both the right and left halves of the abdomen and the right lateral-lateral projection. The complete study was not conducted on all animals to reduce radiation exposure to the operators and to expedite surgical intervention when the concretion was quickly identified. Projection settings ranged from 100 to 150 kV and 12.0 to 40.0 mAs, with the transmitter placed approximately 30 cm from the animal, and the 35x29 cm reception plate maintained in contact with the animal.

Parameters evaluated

Animals were assessed based on breed and weight (kg), and body condition scores were analyzed using a scale from 1 to 9 (Henneke et al., 1983), categorizing them into three groups: lean (1 to 3), normal (4 to 6), and obese (7 to 9).

Radiographic evaluations included the absence or presence of mineral densities suggestive of enterolithiasis, diagnostic projections used (latero-lateral and/or dorsoventral) (Figure 1), characteristics of the enterolith (oval or irregular), total number of concretions, location of the concretion, and the presence of gas in the gastrointestinal tract.

Figure 1. Positioning of the radiographic equipment for the latero-lateral and dorsoventral projections.

The degree of gas distension was assessed by examining the distension of the flanks, radiographic evidence of gas, and radiographic penetration quality, supplemented by direct inspection during laparotomy. It was classified as absent, mild, moderate, or intense (Table 1).

Table 1
Parameters used to classify abdominal distension in horses.

Absent	Visualization of the paralumbar fossae; adequate radiographic penetration; no image compatible with gas; concave appearance of the equine abdomen when positioned in dorsal recumbency; and absence of gas distension in the intestinal segments during direct inspection at laparotomy.
Mild	Description: Visualization of the paralumbar fossae; adequate radiographic penetration with mild presence of gas; mild abdominal bulging when the equine is positioned in dorsal recumbency; and mild gas distension in the intestinal segments during direct inspection at laparotomy.
Moderate	Description: Reduced visualization of the paralumbar fossae; adequate radiographic penetration with moderate presence of gas; moderate abdominal bulging when the equine is positioned in dorsal recumbency; and moderate gas distension in the intestinal segments during direct inspection at laparotomy.
Intense	Description: Absence of visualization of the paralumbar fossae; inadequate radiographic penetration with intense presence of gas; loss of abdominal concavity when positioned in dorsal recumbency; intense gas distension in the intestinal segments during direct inspection at laparotomy.

Surgical findings

Surgical evaluations were conducted concerning the diagnosis of the control group and the enterolithiasis group. In the enterolithiasis group, the presence, shape, number, and location of enteroliths were determined. Outcomes considered included whether the animal was discharged, died, or required euthanasia.

Statistical analysis

Data were tabulated in Excel and analyzed statistically using R software (R Core Team [R], 2021). The initial evaluation involved comparing the agreement between radiographic image data, the absence or presence of an image suggestive of enterolithiasis, findings from exploratory laparotomy, and confirmation of the condition. Due to deviations from normality, quantitative variables were analyzed using the Mann-Whitney test, and qualitative variables were assessed with the Chi-Square test, thereby identifying significant parameters for further multiple analyses by setting the p-value threshold (Table 2). Only animals in the enterolithiasis group were included in this analysis because those in the control group showed 100% agreement, which could overestimate the effect on the data.

Table 2
Significant parameters for multiple analysis by defining the p-value.

Variable	P-value
X-ray	<0.001
Final diagnosis	NA
Categorical body condition score	0.012
Clinical signs	0.876
Presence of gas	0.027
Enterolith location	0.586
Outcome	1.000
Number of enteroliths on imaging	0.001
Number of enteroliths during surgery	0.673
Weight (kg)	0.044

Subsequent analysis utilized variables that demonstrated statistical significance in the initial assessments. Multiple Correspondence Analysis (MCA) was conducted to explore the simultaneous association of radiographic findings with potential factors influencing the accuracy of this examination (Di Franco, 2016; Nenadic & Greenacre, 2005). The MCA was performed using the FactoMineR and factoextra R packages (Kassambara & Mundt, 2020; Lê et al., 2008).

For the MCA, categorical variables were organized as follows: body condition scores, initially on a scale from 1 to 9 (Henneke et al., 1983), were re-categorized into three groups lean (1-3), normal (4-6), and obese (7-9). Clinical signs were divided into two categories, presence or absence. Radiographic findings were categorized based on whether an image suggestive of enterolithiasis was present or absent. The presence of gas was classified into four categories: absent, mild, moderate, and intense. The final diagnosis was categorized as either enterolithiasis or no enterolithiasis, and the outcome for the animals was categorized as either discharge or death.

Variables, categories, and individuals were represented as a cloud of points within a plane defined by axes of increasing variability. The positions of the categories on the plane represent their associations with the axes, with greater discrimination indicated by greater distances from the origin of the graph. Proximity between individual points suggests similar profiles in relation to the study variables.

Results and Discussion

From June 2022 to October 2023, at the Guadalupe Veterinary Clinic in Rio Grande do Sul, 92 horses were treated for colic syndrome or a history of recurrent abdominal pain. Of these, 32 animals met the inclusion criteria for the study and had their medical records evaluated. The study was divided into two groups: 12 horses comprised the control group, and 20 formed the enterolithiasis group. The radiographic examination required between 19 to 48 projections per horse. This variation in the number of projections was due to the small size of the reception plate, necessitating multiple projections. However, in cases where animals exhibited significant discomfort, the examination was halted once the radiographic images suggested enterolithiasis, and the patient was promptly prepared for surgery. Concerning the consensus on the absence or presence of mineral density suggestive of enterolithiasis, the veterinarians who reviewed the images reached agreement in 18 of the 20 cases in the enterolithiasis group. Two cases resulted in disagreement among the reviewers, with two out of three indicating the presence of an image compatible with enterolithiasis. In both instances, enterolithiasis was confirmed during the transoperative period. In the control group, there was a 100% agreement among reviewers regarding the absence of mineral opacity suggestive of enterolithiasis, which was later confirmed by surgical approach.

The control group consisted of 12 horses aged between 4 and 16 years, including 9 males and 3 females. The breeds represented were Arabian (1), Brazilian Equestrian (2), Quarter Horse (1), and Criollo (8). These horses exhibited clinical signs of abdominal discomfort linked to the large intestine and underwent abdominal radiographs that showed no radiopacity suggestive of enterolithiasis. All horses in this group were referred for median laparotomy due to non-responsiveness to clinical treatment and were diagnosed with other conditions affecting the large intestine (Table 3).

Table 3
Surgical findings in the control group.

Number of horses	Final diagnosis
2	Impaction of the large colon
3	Torsion of the large colon
1	Sand colic
2	Displacement of the large colon
1	Fecaloma of the small colon
1	Cecal impaction
1	Impaction of the cecum and large colon associated with displacement of the colon
1	No changes

The enterolithiasis group included 20 horses aged between 4 and 17 years, comprising 14 males and 6 females from the breeds Quarter Horse (2), Brazilian Equestrian (1), and Criollo (17). These horses displayed clinical signs of abdominal discomfort linked to the large intestine or had a history suggestive of enterolithiasis. Radiopacity indicative of enterolithiasis was observed in 17 horses (85.5%), which were subsequently referred for median laparotomy where the diagnosis was confirmed. The remaining three animals (14.5%) in this group, despite lacking radiographs with density images indicative of enteroliths, underwent laparotomy due to unresponsive abdominal discomfort and were found to have enteroliths causing the obstructive condition.

The study showed a predominance of the Criollo breed in both groups (control and enterolithiasis), aligning with its significant presence in Rio Grande do Sul, where there are 425,300 registered specimens according to the Brazilian Association of Criollo Horse Breeders (ABCCC). In contrast, the Quarter Horse breed has 19,800 registered specimens in the state, including purebreds and crossbreds (ABQM). The development of enterolithiasis in Criollo horses may be linked to intensive management practices, particularly among sport horses and those in morphological preparation, where alfalfa, a readily available forage in the state, constitutes a primary roughage source (Santos et al., 2017). Additional factors like the mineral characteristics of soil and water in certain regions may also contribute to the higher incidence of the condition (Hassel et al., 1999).

Statistically, significant differences were noted in weight and body condition score, the presence of an image suggestive of enterolith on x-rays, the number of enteroliths visible, and gas distension, all with a p-value of ≤ 0.05.

In the enterolithiasis group, weights ranged from 400 to 580 kg. Of the 20 horses, 18 had a body condition score of 5, indicating ribs not visible but easily felt with no localized fat accumulation. One horse scored an 8 and another a 9, both showing fat accumulation around the ribs, tail base, and neck crest. Technique applicability was reduced for animals with a body condition score above 6 on a scale of 1 to 9, according to the classification of Henneke et al. (1983) (Figure 2) and correspondingly higher weight (Figure 3). In this study, these factors hindered the visualization of enteroliths on the images, but this relationship was not found in the consulted literature. Although abdominal radiography demands higher radiation penetration than for areas such as limbs or the head, underexposure can negatively impact diagnostic accuracy. Regarding this issue, a convenience offered by digital radiology is image processing, which can adjust contrast to compensate for underexposure, thus mitigating one of the main causes of diagnostic errors (Kelleher et al., 2014).

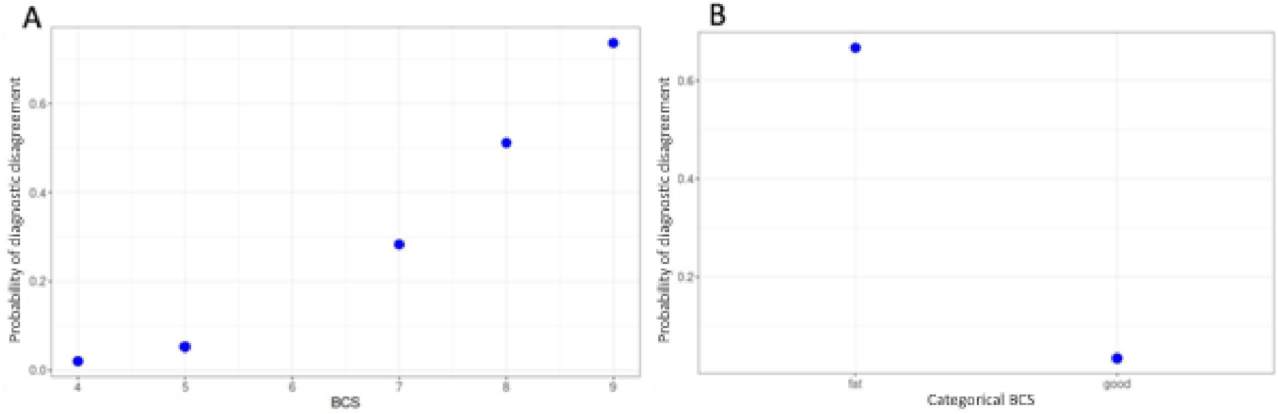

Figure 2. A - Distribution of animals according to body condition score (BCS) assessed using a scale from 1 to 9 (x-axis) and its correlation with the probability of diagnostic disagreement (y-axis). Note that as BCS increases, the curve for diagnostic error increases proportionally; B - Distribution of animals according to the categorical BCS, where horses scoring 1 to 3 are classified as thin, 4 to 6 as normal, and 7 to 9 as fat (x-axis). A clear distribution of groups is noted, with fatter animals exhibiting a higher probability of diagnostic disagreement.

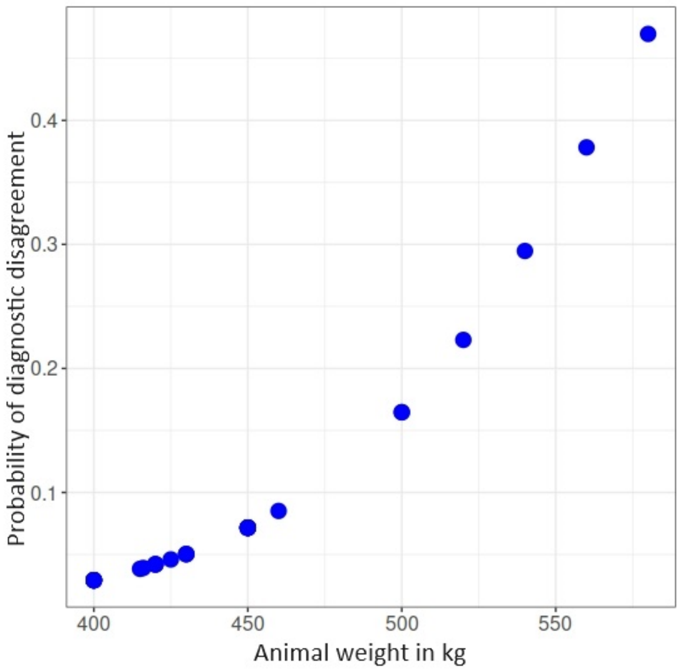

Figure 3. Distribution of animals according to weight in kg (x-axis) and its correlation with the probability of diagnostic disagreement (y-axis), showing that the chance of error in the imaging diagnosis of enterolithiasis increases proportionally with the weight of the animal.

Regarding the radiographic parameters analyzed, a higher occurrence of spherical enteroliths was observed: ten animals exhibited only one spherical concretion, four animals had two spherical concretions, and six animals presented one or multiple irregularly shaped concretions. Enteroliths can vary in shape, texture, and size, with these variations linked to the components involved in their formation (Hassel et al., 2001). Spherical and tetrahedral shapes are most commonly observed (Pierce, 2009), with spherical enteroliths typically being solitary and polytetrahedral enteroliths often indicating multiple concretions (Southwood, 2015).

In this study, 12 horses had one concretion each, five horses had two concretions each, one horse had five concretions, one had 12 concretions, and one horse presented with 40 small concretions clustered around a metallic core (nail), giving the impression of a single large concretion on the radiographic image. Maher et al. (2011) noted in their study on computed abdominal radiography for diagnosing enterolithiasis in horses, which evaluated 142 cases, that animals with a greater number of enteroliths tend to have smaller concretions, potentially complicating the diagnosis compared to animals with a single large enterolith. However, in the current study, the number of enteroliths did not affect the applicability of the technique; it was possible to diagnose animals with either a single or multiple enteroliths. Moreover, it was observed that the presence of more than one concretion correlated positively with the success of the imaging exam.

Of the 20 animals in the enterolithiasis group, 14 were diagnosed using the lateral-lateral projection, three via the dorsoventral projection, and three underwent all projections but showed false-negative results, which were later confirmed during laparotomy. These data were not included in the statistical analysis, as not all projections were performed on all animals due to the need to minimize radiation exposure to the operators.

Regarding the location of the stones and their impact on diagnosis, this study did not identify any statistically significant differences, contrary to findings by Maher et al. (2011). Kelleher et al. (2014) noted higher accuracy of the technique for diagnosing enteroliths in the large colon compared to the small colon. This difference is primarily attributed to the gas distension characteristic of small colon obstructions caused by enteroliths that completely block the lumen of this intestinal segment. Enteroliths typically cause obstructions at points where the intestinal diameter significantly narrows, such as the transition from the right dorsal colon to the transverse colon and the small colon (Southwood, 2019). In this study, laparotomy revealed eight animals with obstructions in the right dorsal colon, five in the transverse colon, and seven in the small colon. As obstructions progress, they can cause lesions from the mass pressing against the intestinal wall, potentially leading to necrosis and intestinal rupture (Cook et al., 2019). One animal in this study presented with a lesion compatible with necrosis in the serous layer of the small colon at the obstruction site but remained surgically viable, was successfully treated, and was discharged postoperatively. Major complications associated with small colon obstructions include inflammation, ischemia, and intestinal rupture (Pierce et al., 2010). These complications may be exacerbated by regions that cannot be exteriorized from the abdominal cavity and by the smaller diameter of this segment, which increases the damage caused by pressure against the intestinal wall (Prange et al., 2019).

In the enterolithiasis group of 20 horses, nine exhibited no abdominal distension. Of these, four were electively referred for radiographic examination and subsequently for laparotomy, following a positive radiographic diagnosis coupled with a history consistent with enterolithiasis (Figure 4), which included recurrent abdominal pain and defecation of enteroliths. Eight animals exhibited mild distension, one displayed moderate distension, and two experienced intense distension. Of the horses with intense distension, one had a BCS of 5 and was pre-surgically diagnosed with an enterolith in the small colon (Figure 5). The other, with a BCS of 8, showed a false negative on abdominal radiography and was referred for exploratory laparotomy after failing to respond to clinical treatment and continuing to exhibit discomfort. During surgery, an enterolith was identified in the right dorsal colon as the cause of the clinical picture. This finding indicates that the body condition score can be an important factor in achieving accurate diagnoses, highlighting the need for vigilance on the part of the clinician regarding false negatives in obese animals. However, further research with a larger sample size is necessary to conclusively link abdominal distension and body condition score with positive radiographic diagnosis and the specific location of the enterolith. It has been established that gas distension adversely affects the diagnosis of enteroliths via abdominal radiography, particularly for enteroliths in the small colon. These are challenging to diagnose due to significant gas accumulation that obstructs the colon (Prange et al., 2019) and the central anatomical position of the small colon in the abdomen, which is often obscured by compacted ingesta, complicating the identification of enterolith rims (Maher et al., 2011).

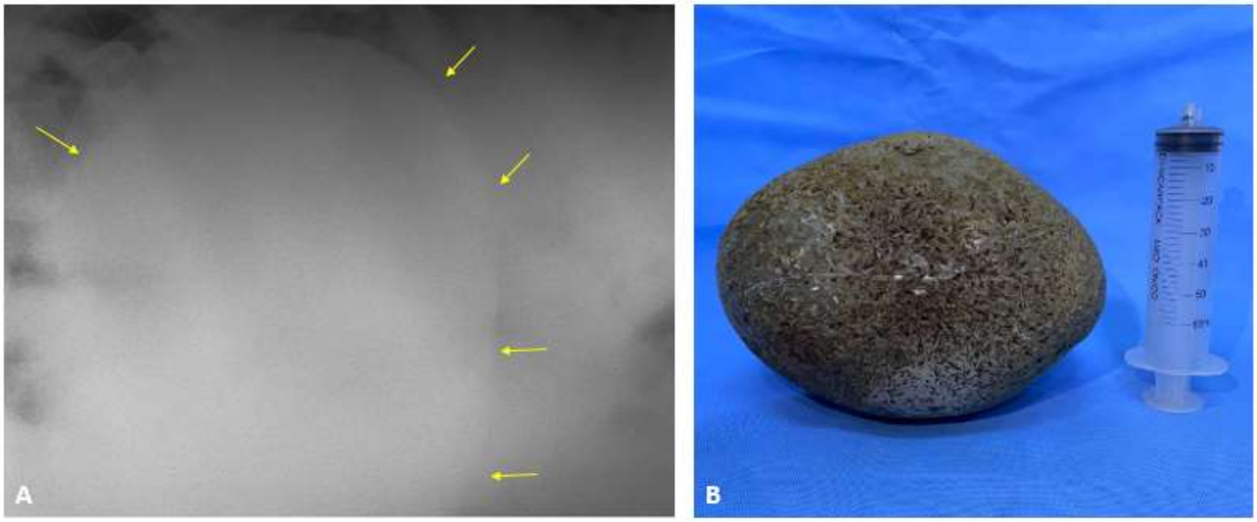

Figure 4. A - Abdominal radiography (dorsoventral projection) with an image compatible with an enterolith in the right dorsal colon in a patient without abdominal distension; B - Enterolith after surgical removal through laparotomy and enterotomy in the right dorsal colon. Arrows indicate the delineation of the concretion.

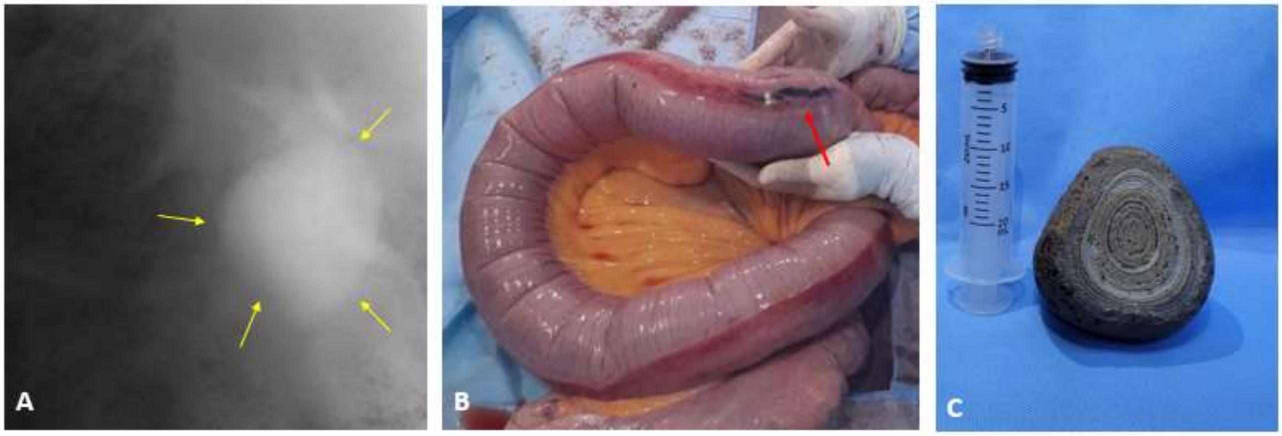

Figure 5. A - Abdominal radiography (latero-lateral projection) with an image compatible with an enterolith in the smaller colon in a patient with intense abdominal distension; B - Intraoperative image showing gas distension of the smaller colon; C - Enterolith after surgical removal through laparotomy and enterotomy in the smaller colon. Yellow arrows indicate the delineation of the concretion. Red arrow indicates a lesion with necrotic appearance on the intestinal serosa at the site of the obstruction.

When multiple structures are superimposed, such as gas-filled intestinal loops, changes in the opacity of a given area on the final radiograph may occur. This phenomenon, known as the summation shadow, can diminish the radiopacity of the enterolith. Similarly, areas where gas is combined with soft tissue structures may exhibit a fat-like opacity, which can compromise image formation (Nelson & Pease, 2019). In animals experiencing intense abdominal distension due to gas and the accumulation of ingesta in obstructive conditions, these factors can lead to a false negative result on the abdominal radiograph.

After analyzing the correlation between the presence of an image suggestive of enterolith on the X-ray and its confirmation during exploratory laparotomy, MCA was conducted. This analysis evaluated how the variables related to the success or failure of the imaging exam in diagnosing the condition. Only the animals in the enterolithiasis group, confirmed to have enteroliths, were included in the MCA, totaling 20 animals. The control group, which consisted of acute abdomen cases due to causes other than enterolithiasis, was excluded from this stage as the negative imaging result was confirmed in 100% of these cases. The x and y axes derived from the MCA explained 43% and 18.8% of the variance, respectively. These axes were referenced against the variable labeled 'correct', which assessed the accuracy of the imaging exam in detecting enteroliths compared to the gold standard, laparotomy. This analysis provided better discrimination of individuals with variables closely related to the first axis. The MCA identified the most prevalent parameters affecting the correct or incorrect diagnosis of enterolithiasis using X-rays, as illustrated in Figure 6. The first dimension of the analysis divided the plane into two regions: one on the right, primarily consisting of negative cases animals in which the X-ray did not suggest the presence of enteroliths, yet concretions were discovered during laparotomy (3 animals); and another on the left, including animals that showed a positive image on X-ray and whose enteroliths were located during surgery (17 horses). The analysis of category positions in the reduced space indicated distinct profiles for the groups based on the accuracy of the imaging diagnosis. Cases where the imaging failed to diagnose enterolithiasis were characterized by moderate to intense gas and animals categorized as obese in their body condition score. Conversely, successful imaging cases typically involved animals with no to mild gas and a normal body condition score. Regarding the presence of clinical signs, there was a tendency for proximity with cases of imaging errors, although no clear division was evident based on this parameter.

Four animals in the enterolithiasis group were referred for non-emergency laparotomy upon arrival in stable condition for abdominal radiography. Early diagnosis, when the horse is systemically stable, can significantly improve prognosis and reduce costs for the client (Cook & Hassel, 2014). In these cases, the examination was prompted by a history of recurrent colic in three animals, one of which had previously defecated an enterolith. Meanwhile, 16 other animals in the same group underwent radiography and were referred for urgent exploratory laparotomy due to clinical signs of abdominal discomfort such as scratching and rolling, as well as severe abdominal distension, intestinal hypomotility, and absence of defecation.

Nineteen animals in the enterolithiasis group were discharged, while one animal was euthanized due to complications arising from postoperative colitis. In the control group, one animal died in the immediate postoperative period due to hemodynamic complications from a 360-degree colon twist.

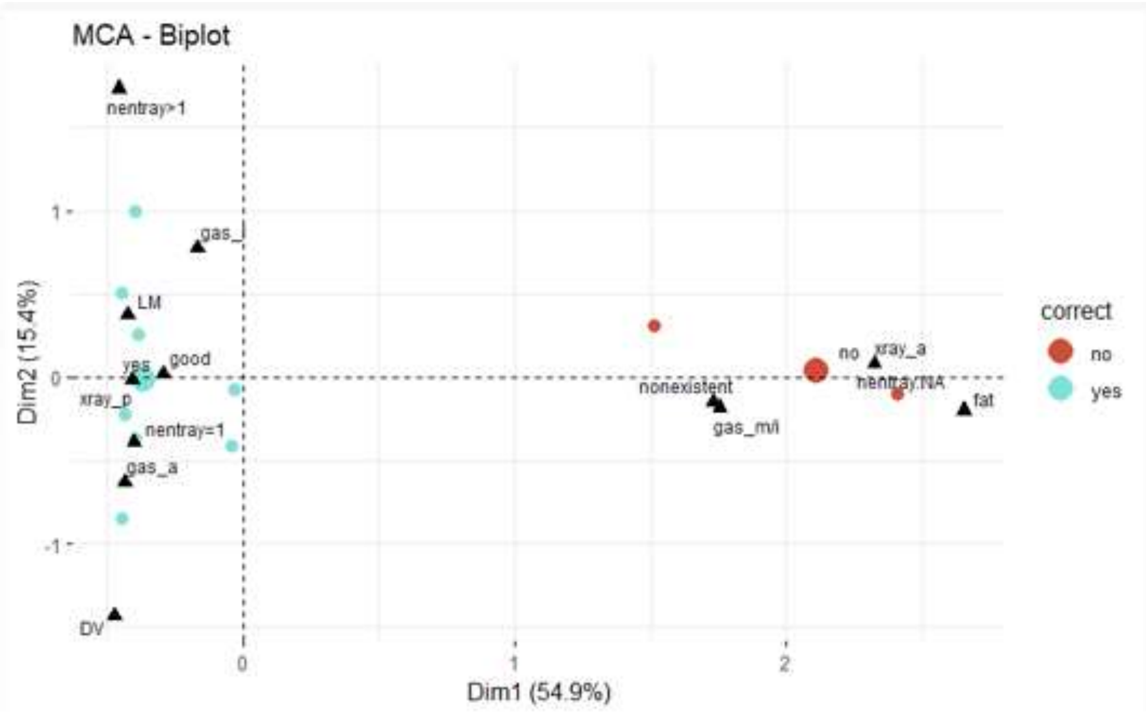

Figure 6. Multiple correspondence analysis using the variable 'correct' (level of accuracy of the imaging exam compared to surgical findings) as a basis and correlating with statistically significant variables in the initial analysis (categorical body condition score, presence of gas, x-ray result, and number of enteroliths in the image). Red circles represent the animals in which no image suggestive of enterolith was obtained (no) and blue circles represent horses with a suggestive image on x-ray and confirmation of the enterolith diagnosis in surgery (yes). Significant parameters are represented by triangles and include: obese (Fat) and normal (good) animals according to the categorical body condition score; presence of gas absent (gas_a), light (gas_l), moderate and/or intense (gas_m/i); presence of an x-ray image suggestive of enterolith present (xray_p) or absent (xray_a); number of enteroliths visualized in the image equal to one (nentray=1), more than one (nentray>1) or absent (nentrayNA); and, finally, the projection used for the detection of the enterolith: latero-medial (LM), dorsoventral (DV) or not found (nonexistent). A marked division can be observed between the groups of animals in which it was possible to diagnose the enterolith in the imaging exam and those with absence of image when looking at the graph on the x-axis. For body condition score, only the categorical approach was used to improve data visualization in the image.

A study by Bianchi et al. (2020) assessed 114 horses necropsied in southern Brazil, primarily from the metropolitan region of Porto Alegre, RS, focusing on non-infectious gastrointestinal diseases. In this study, enterolithiasis was identified as the third leading cause of death, affecting 20 of the 114 horses evaluated; 11 of these 20 horses presented with visceral perforation and peritonitis due to prolonged obstruction. These data highlight the significance of enterolithiasis as a cause of colic in horses in southern Brazil. Additionally, a review by Hassel et al. (1999) reported a 6% recurrence rate of enterolithiasis in 900 treated horses, revealing the importance of educating owners about the etiology of the condition and implementing optimal dietary and environmental management to prevent enterolith formation. Identifying risk factors in postoperative animals is crucial to prevent the formation of new concretions.

Conclusions

This study demonstrated that digital abdominal radiography serves as an important auxiliary method for the pre-surgical diagnosis of equine enterolithiasis. The feasibility of this diagnostic approach was confirmed, regardless of the obstructed intestinal segment or the number of enteroliths present, with notably easier observation in animals harboring more than one concretion. However, it is important to exercise caution when interpreting images from obese horses or those exhibiting abdominal distension due to gas, as these conditions have been associated with false-negative diagnoses. The inclusion of a control group, in which radiographic evaluations consistently ruled out the presence of enteroliths, coupled with surgical confirmation in both the enterolithiasis and control groups, highlights the value of this diagnostic method, which allows for early therapeutic intervention and enhances the prognosis.

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References

Bianchi, M. V., Ribeiro, P. R., Stolf, A. S., Bertolini, M., Laisse, C. J., Sonne, L., Driemeier, D., & Pavarini, S. P. (2020). Epidemiological and pathological aspects of noninfectious diseases of the gastrointestinal tract in 114 horses in Southern Brazil. *Pesquisa Veterinária Brasileira, 40,* 4, 242-253. doi: 10.1590/1678-5150-PVB-6516

Cook V. L., Blikslager, T., Marshall, J. F. (2019) Principles of intestinal injury and determination of intestinal viability. In J. A. Auer, J. A. Stick, J. M. Kummerle, & T. Prange (Orgs.), *Equine surgery* (Cap. 34, pp. 529-535). St. Louis.

Cook V. L., & Hassel, D. M. (2014). Evaluation of the colic in horses: decision for referral. Veterinary Clinics: *Equine Practice, 30*(2), 383-398. doi: 10.1016/j.cveq.2014.04.00

Di Franco, G. (2016). Multiple correspondence analysis: one only or several techniques?. *Quality & Quantity, 50*(3), 1299-1315. doi: 10.1007/s11135-015-0206-0

Hassel, D. M., Langer, D. L., Snyder, J. R., Drake, C. M., Goodell, M. L., & Wyle, A. (1999). Evaluation of enterolithiasis in equids: 900 cases (1973–1996). *Journal of the American Veterinary Medical Association, 214*(2), 233-237. doi: 10.2460/javma.1999.214.02.233

Hassel, D. M., Schiffman, P. S., & Snyder, J. R. (2001). Petrographic and geochemic evaluation of equine enteroliths. *American Journal of Veterinary Research, 62*(3), 350-358. doi: 10.2460/ajvr.2001.62.350

Henneke, D. R., Potter, G. D., Kreider, J. L., & Yeates, B. F. (1983). Relationship between condition score, physical measurements and body fat percentage in mares. *Equine Veterinary Journal, 15*(4), 371-372. doi: 10.1111/j.2042-3306.1983.tb01826.x

Kassambara, A., & Mundt, F. (2020). *Extract and visualize the results of multivariate data analyses [R package factoextra version 1.0.7].*

Kelleher, M. E., Puchalski, S. M., Drake, C., & Le Jeune, S. S. (2014). Use of digital abdominal radiography for the diagnosis of enterolithiasis in equids: 238 cases (2008-2011). *Journal of the American Veterinary Medical Association, 245*(1), 126-129. doi: 10.2460/javma.245.1.126

Keppie, N. J., Rosenstein, D. S., Holcombe, S. J., & Schott, H. C. (2008). Objective radiographic assessment of abdominal sand accumulation in horses*. Veterinary Radiology & Ultrasound, 49*(2), 122-128. doi: 10.1111/j.1740-8261.2008.00337.x

Lê, S., Josse, J., & Husson, F. (2008). FactoMineR: an R package for multivariate analysis. *Journal of Statistical Software, 25*(1), 1-18. doi: 10.18637/jss.v025.i01

Maher, O., Puchalski, S. M., Drake, C., & Le Jeune, S. S. (2011). Abdominal computed radiography for the diagnosis of enterolithiasis in horses: 142 cases (2003-2007). *Journal of the American Veterinary Medical Association, 239*(11), 1483-1485. doi: 10.2460/javma.239.11.1483

Nelson, C. N., & Pease, A. (2019). Radiography. In J. A. Auer, J. A. Stick, J. M. Kummerle, & T. Prange (Orgs.), *Equine surgery* (Cap. 68, pp. 1156-1173). St. Louis.

Nenadic, O., & Greenacre, M. (2005). Computation of multiple correspondence analysis, with code in R. *UFP Working Papers, 887*(1). doi: 10.2139/ssrn.847698

Pierce, R. L. (2009). Enteroliths and other foreign bodies. *Veterinary Clinics: Equine Practice, 25*(2), 329-340. doi: 10.1016/j.cveq.2009.04.010

Pierce, R. L., Fischer, A. T., Rohrbach, B. W., & Klohnen, A. (2010). Postoperative complications and survival after enterolith removal from the ascending or descending colon in horses. *Veterinary Surgery, 39*(5), 609-615. doi: 10.1111/j.1532-950X.2010.00647.x

Prange, Y., Blikslager, T. A., & Rakestraw, C. P. (2019). Transverse and small colon. In J. A. Auer, J. A. Stick, J. M. Kummerle, & T. Prange (Orgs.), *Equine surgery* (Cap. 38, pp. 621- 631). St. Louis.

R Core Team (2021). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing.

Santos, A. C., Curcio, B. D. R., Finger, I. S., Castro, J., Jr., & Nogueira, C. E. W. (2017). Enterolithiasis in Crioulo Horses. *Acta Science Veterinary 45*(1), 1-5. doi: 10.22456/1679-9216.85232

Southwood, L. (2015). Digestive system and peritoneal disease. In L. L. Southwood, & A. P. Wilkins (Orgs.), *Equine emergency and critical care medicine* (Cap. 1, pp. 27-154). Boca Raton.

Southwood, L. (2019). Large colon. In J. A. Auer, J. A. Stick, J. M. Kummerle, & T. Prange (Orgs.), *Equine surgery* (Cap. 37, pp. 591-621). St. Louis.