Journal of Equine Veterinary Science 139 (2024) 105126

Contents lists available at ScienceDirect

Journal of Equine Veterinary Science

journal homepage: www.elsevier.com/locate/jevs

Original Research

Dry matter concentration, particle size distribution and sand presence in faeces from horses with and without colic

Cecilia E. Müller *

Department of Applied Animal Science and Welfare, Swedish University of Agricultural Sciences, Uppsala, PO Box 7024, SE-75007 Uppsala, Sweden

A R T I C L E I N F O

Keywords:
Equine
Gas colic
Impaction
Sand colic

A B S T R A C T

A study comprising 74 colic and 74 control horses admitted to an animal hospital was performed. Faecal samples were collected and analysed for dry matter concentration, particle size distribution using wet-sieving, and sand presence through a sand sedimentation test. Data on horse breed, age, gender and basic feeding variables was collected and analysed using χ^2-tests. Faecal dry matter concentration, particle size distribution and sand score was compared between colic and non-colic horses, and between horses with different colic types, using one-way ANOVA. Results showed that colic and non-colic horse groups were similar in breed, age, gender and basic feeding variables. Faecal dry matter concentration, particle size distribution and sand score were similar among colic and non-colic horses. Horses diagnosed with "unknown colic cause" had higher proportion of particles >0.5 <1.0 mm size compared to horses with colic due to impactions in caecum or colon, torsion or gas accumulation (P<0.05), but this difference was very small and most likely not of biological importance. Faecal dry matter concentration and sand score were similar among horses with different types of colic. Increased knowledge of the composition of particles of different size in equine faeces may enhance our understanding of digesta passage rate in colic and non-colic horses, which is needed to develop preventative measures of certain types of colic.

1. Introduction

Colic (abdominal pain) has been reported to be one of the most frequent causes of requirement of veterinary care and/or euthanasia of horses [1-5]. In addition to the negative impact of colic on health and welfare of the affected horse, colic incidences also affect overall economy in the horse industry negatively due to high costs for veterinary treatment and loss of horses when the colic outcome is lethal [3,6]. Knowledge that can improve the understanding, prevention, diagnosis and treatment of colic in horses is therefore of interest. Clinical signs of colic may arise from different disturbances in the gastro-intestinal tract, *e.g.* gas and/or sand accumulation and impactions in the caecum and/or the colon [5]. In colic cases, the volume and physical characteristics of faeces such as perceived moisture content (assessed by structure and visual appearance) and presence of long or undigested particles in faeces are often evaluated by the examining veterinarian and/or the horse owner, as a diagnostic aid in field conditions [7,8]. In one study [7], faecal characteristics was reported to differ between horses with different types of colic and between surviving and non-surviving colic horses. The characteristics of faeces noted in that study was consistency, colour, quantity, presence of grain, straw or foreign bodies, in addition to the estimated time since the last defecation at the clinical examination. In horses with obstructive colic, faecal consistency was described as "small and dry" [7], and in horses with colon impaction the digesta has been described as dehydrated [8]. However, systematic studies of if and how faecal characteristics differ in horses with and without colic, or between different types of colic, are scarce. In addition, some of the abovementioned faecal characteristics could be estimated more precisely with easily accessible and rapid tools. These may include (but not be limited to) dry matter (DM) concentration, particle size distribution [9,10], and presence of sand [11,12,13] in the faeces. To the authors' knowledge, no data has previously been published on DM concentration in faeces from horses with colic. Mean faecal particle size has been reported to be smaller in horses with large colon impaction colic compared to in non-colic horses [14]. Sand sedimentation tests of faecal samples has been reviewed and were reported as lacking both specificity and sensitivity for diagnosing sand colic (due to sand accumulation in the hindgut) in horses [13], and sand can be present in faeces from horses without sand colic [11]. Despite this, these sedimentation tests are still in use in practice [13]. This illustrates the importance of performing

* Corresponding author.
E-mail address: Cecilia.Muller@slu.se.

https://doi.org/10.1016/j.jevs.2024.105126
Received 5 March 2024; Received in revised form 17 May 2024; Accepted 6 June 2024
Available online 7 June 2024
0737-0806/

systematic studies of similar tests or assessments of faecal samples before using them as diagnostic tools. The aim of the current study was therefore to evaluate if horses with clinical signs of colic had different dry matter concentration, particle size distribution and sand presence in their faeces compared to horses without colic. The aim was also to compare the same faecal variables in horses diagnosed with different colic types.

2. Materials and methods

This study was part of a larger study, which was approved by the Uppsala animal welfare ethics committee (license number: Dnr 68/16). The study was designed as a prospective case-control study of equine patients at the Equine clinic at Evidensia Animal Hospital, Helsingborg, Sweden. The study started in January 2016 and ended in January 2017. Participation in the study was voluntary, and owners of horses admitted to the hospital were asked to fill in and sign a written consent form at admission.

2.1. Horses and colic types

All horses were recruited to the study when they were admitted to the equine clinic at Evidensia Animal Hospital, Helsingborg, Sweden. The horses were, dependent on the reason for being admitted to the animal hospital, included as a colic (horses showing clinical signs of colic) or non-colic horse (no illness related to the gastro-intestinal tract). Both colic and non-colic horses were included in the study during the full year. Colic type was diagnosed by the examining veterinarian, and only horses with colic due to impaction in caecum and/or colon, gas colic and/or torsion, sand colic and unknown/unspecific colic (where no clear cause for the colic could be identified) were included in the study (excluding parasite or pharmaceutically induced colic, gastric issues, peritonitis, and trauma-induced abdominal hernia). In total 74 case (colic) and 74 control (non-colic) horses were included in the study. Information about horse breed, gender, age, type of forage used, if concentrates were fed, if the horse had access to straw and if the horse had been examined and/or treated by a veterinarian for colic prior to admission (within the same colic episode) was obtained from the horse owner at the visit to the hospital. Within colic and non-colic groups, the horses were categorized with respect to its breed and age. Each horse was placed in one of the following five breed categories: European warmblood riding horse, American and Iberian breeds, Standardbreds and Thoroughbreds, Icelandic horse and pony breeds, or cold-blood breeds. Each horse was also placed in one of the following five age groups: 1-4, 5-10, 11-15, 16-20 and 21-26 years old.

2.2. Faecal samples

Faecal samples were taken during rectal examination or from freshly passed faeces in a loose box (within 1 hour) for each horse upon arrival to the hospital, put in double plastic bags and sent by post to the Laboratory at the Department of Applied Animal Science and welfare, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden. Upon arrival to the laboratory, the faecal samples were frozen at -21°C. Samples were then thawed over night at room temperature (approximately +20°C) before analysis.

2.2.1. Dry matter content in faeces

Dry matter (DM) content of faeces was determined by drying 100 g of the faecal sample for 18 hours in 55°C in a forced-air cabinet. The samples were then air-equilibrated with the ambient air humidity for about 4-6 hours before weighing. Before drying, faecal balls were disintegrated and mixed (by hand) to avoid uneven drying and crust formation of faecal balls during drying. The DM content was calculated as (weight after drying)/(weight before drying) ×100 and given in percent.

2.2.2. Particle size distribution

The particle size distribution in faecal samples was determined by wet sieving [15] as modified by Müller (2009) [9]. Faeces (100 g) was mixed with 500 ml of tap water to a slurry, which was poured over a stack of sieves (DIN 4188, Rudolph Grave AB, Stockholm, Sweden). Four different sieve dimensions were used (2.0 mm, 1.0 mm, 0.5 mm and 0.2 mm) and stacked upon each other with the largest dimension at the top and the remaining sieve dimensions in descending order. The liquid from the first pour over the sieve stack was collected under the bottom sieve and poured over the stack of sieves three more times (four times in total). The stack of sieves was then left to drip off for five minutes, after which each sieve was weighed with the faecal particles trapped on it. The dry weight of the sieve was subtracted to achieve the weight of the wet faecal particles on each sieve. The fraction of particles <0.2 mm or otherwise lost at sieving was calculated by difference. The proportion of each particle size fraction collected on the different sieves and the fraction <0.2 mm was then calculated and given in proportion of the sample.

2.2.3. Sand sedimentation test

Presence of sand in faecal samples was examined by a sand sedimentation test [11] with a minor modification: 100 g faecal sample was diluted with 500 ml of tap water, mixed to a slurry and poured into a rectal examination plastic glove. The glove was left hanging vertically for 30 minutes for the slurry to sediment. The thumb of the glove was excluded as it was rarely filled, and therefore only four fingers were graded instead of five as originally described [11]. The thumb was excluded by pushing it inside the glove after the faecal slurry had been poured into the plastic glove, but before it was left to sediment. The sand content of the four remaining fingers of the glove was then graded from 0 to 3 according to; 0 - no sand, 1 - some sand visible, 2 - moderate amount of sand clearly visible and 3 - a lot of sand, easily visible and palpable, and then summed up to a maximal sand score of 12.

2.3. Statistics

Chi-square tests were performed for breed type, age group, gender, type of forage used, if the horse had access to straw and if the horse was fed any concentrates for colic- and non-colic horse groups as a quality control of the background data and for checking comparability of the groups. A one-way ANOVA using the general linear models (GLM) procedure in SAS version 9.4 for Windows (SAS Institute, Cary, USA) was performed for DM concentration, particle size distribution and sand score in faecal samples in colic and non-colic horses, and in horses with or without different types of colic. Differences were accepted at $P<0.05$. Descriptive statistics were used to describe dry matter concentration in faecal samples from horses with and without different colic types and presented as average, minimum, median and maximum values.

3. Results

3.1. Horses

Age groups were similarly distributed between colic ($n = 6$ age 1–4 years, $n = 33$ age 5–10 years, $n = 22$ age 11–15 years, $n = 10$ age 16–20 years, $n = 3$ age 21–26 years) and non-colic ($n = 6$ age 1–4 years, $n = 45$ age 5–10 years, $n = 14$ age 11–15 years, $n = 7$ age 16 to 20 years, $n = 2$ age 21–26 years) horses with $\chi^2 = 4.35$ ($N = 148$, $P = 0.36$). The breed categories were distributed equally between colic ($n = 43$ European warmblood riding horses, $n = 15$ Icelandic horses, pony breeds and crossbred ponies, $n = 8$ Standardbreds and Thoroughbreds, $n = 5$ American and Iberian breeds, $n = 3$ cold-blood breeds) and non-colic ($n = 49$ European warmblood riding horses, $n = 17$ Icelandic horses, pony breeds and crossbred ponies, $n = 3$ Standardbreds and Thoroughbreds, $n = 4$ American and Iberian breeds, n=1 cold-blood breeds) horses with $\chi^2 = 3.90$ ($N = 148$, $P = 0.42$). The genders were distributed equally between colic $n = 44$ mares, $n = 29$ geldings, $n = 1$ stallion) and non-colic ($n = 40$ mares, $n = 33$ geldings, $n = 1$ stallion) horses with $\chi^2 = 0.45$ ($N = 148$, $P = 0.80$).

In the colic group comprising 74 horses, 18 horses were diagnosed with impaction in caecum and/or colon, 21 horses with gas colic and/or torsion, 7 with sand colic and 28 with unknown/unspecific colic. Within the colic group, 45 (of 74) horses had been examined by a veterinarian for colic prior to admission to the hospital. Of these, 23 horses had been treated with antispasmodic pharmaceuticals, 20 with fluids through naso-gastric intubation, 13 with intravenous fluids, 12 with analgesics, and 1 with laxatives.

3.2. Feeds and feeding

Use of different forage types (hay, haylage, silage or more than one forage type), feeding concentrates, and giving the horse access to straw was similar for colic and non-colic horses (Table 1). Haylage was the single most common forage type for both groups (Table 1).

3.3. Faecal samples

Some of the faecal samples were very small and did not contain sufficient material for correct determination of dry matter content and/or particle size distribution. This resulted in 134 horses (67 colic and 67 non-colic horses) being included in the results for faecal characteristics.

3.3.1. Faecal dry matter content

Dry matter content in faeces from colic and non-colic horses was similar ($P = 0.46$), and was on average 20.5 % for colic and non-colic horses. Faecal dry matter content did not differ in horses with different types of colic (Table 2). The maximum faecal DM concentration was 406 g per kg DM and was found in a horse with colon impaction, while the lowest faecal DM concentration was 117 g per kg DM and was found in a non-colic horse.

3.3.2. Faecal particle size distribution

Faecal particle size distribution was similar ($P > 0.25$) in colic and non-colic horses (Fig. 1). Comparisons of particle size distribution in faeces from horses with different colic types showed that horses with unknown colic type/cause had a higher proportion of faecal particles trapped on the sieve with mesh size 0.5 mm than horses with other colic types, except for sand colic (Fig. 2). This difference was however very small (< 1 % difference).

Table 1
Type of forage, if straw was available and if concentrates were fed to colic- and non-colic horses. Percentages in brackets represent proportion within colic or non-colic horse group.

Feeding variables	Colic horses, n (%)	Non-colic horses, n (%)
Type of forage ($N = 142$[1])		
Hay	19 (26)	14 (20)
Haylage	44 (60)	50 (72)
Silage	7 (10)	3 (4)
More than one forage type	3 (4)	2 (3)
χ^2	2.83	
P	0.42	
Access to straw (N=148)		
Yes	27 (36)	24 (32)
No	47 (64)	50 (68)
χ^2	0.27	
P	0.60	
Fed concentrate feeds (N=148)		
Yes	63 (85)	62 (84)
No	11 (15)	12 (16)
χ^2	0.05	
P	0.85	

[1] missing data for one colic and five non-colic horses

Table 2
Dry matter content (g per kg) in faeces from non-colic horses and from horses with different types of colic ($N = 134$).

	Average	Standard deviation	Minimum	Maximum	Median
Non-colic (n=67)	202	43.8	117	385	197
Unknown colic type/cause (n=28)	204	32.5	131	246	207
Impaction caecum and/or colon (n=18)	207	59.1	144	406	189
Gas colic, torsion (n=21)	215	47.7	145	330	203
Sand colic (n=7)	204	22.2	167	245	205
P	0.89				
SEM	17.5				

3.3.3. Faecal sand score

Average faecal sand score was 2 and was similar in colic and non-colic horses ($P = 0.25$). The distribution of sand score 0 to 12 in faeces from colic and non-colic horses is reported in Fig. 3. Average sand score in faecal samples from horses with different colic types was similar (Table 3). Sand was present in faecal samples from four of the seven horses diagnosed with sand colic (57 %), and in 43 of the 67 (64 %) samples from non-colic horses (Fig. 3).

4. Discussion

4.1. Horses

Colic and non-colic horse groups were similar in age class, breed type, gender and basic feeding data. Breed, age and gender has been reported to influence the risk for colic in horses [16], and feed ration composition (and digestibility) can impact both colic risk [1-5] and faecal particle size [10,15,17,18]. As the colic and non-colic groups did not differ in breed, age, gender and overall feed ration composition, they were regarded as comparable in the current study. It is possible that the studied population had an unknown bias compared to the horse population in general, as study participation was voluntary and limited to a restricted time period. This could limit the applicability of the results to other horse populations. Another limitation of the study was that factors that may have had an impact on the results, such as amount of consumed water and/or feed or the time period since last feed and/or water intake before admission to the hospital, was not known. If, or how, any treatment of the colic horses prior to arrival at the hospital affected faecal DM or particle size distribution was unknown, which was also a limitation of the study.

4.2. Faecal dry matter concentration and visual consistency

The faecal DM concentration was on average 205 g per kg faeces and was similar in colic and non-colic horses. The faecal DM concentration was within the previously reported range of 180 to 240 g per kg in non-colic horses [10,19,20,21,22,23]. Faeces from horses with impaction or obstruction colic have been described as “small and dried-up” in previous reports [7,8], but no data on DM concentration in faeces (or caecal or colonic contents) from colic horses has been found in the literature. Dry matter concentration of faeces have been reported to be almost 10 percent higher (270 vs. 190 g per kg) when horses were stabled and fed hay, compared to when they were kept at pasture [24]. Although the horses in that study did not develop colic after being stabled, the large intestinal motility (detected using transcutaneous ultrasonography) was slower, especially in the left colon [24,25]. A slower passage rate of the digesta can be speculated to contribute to an increased risk of colon

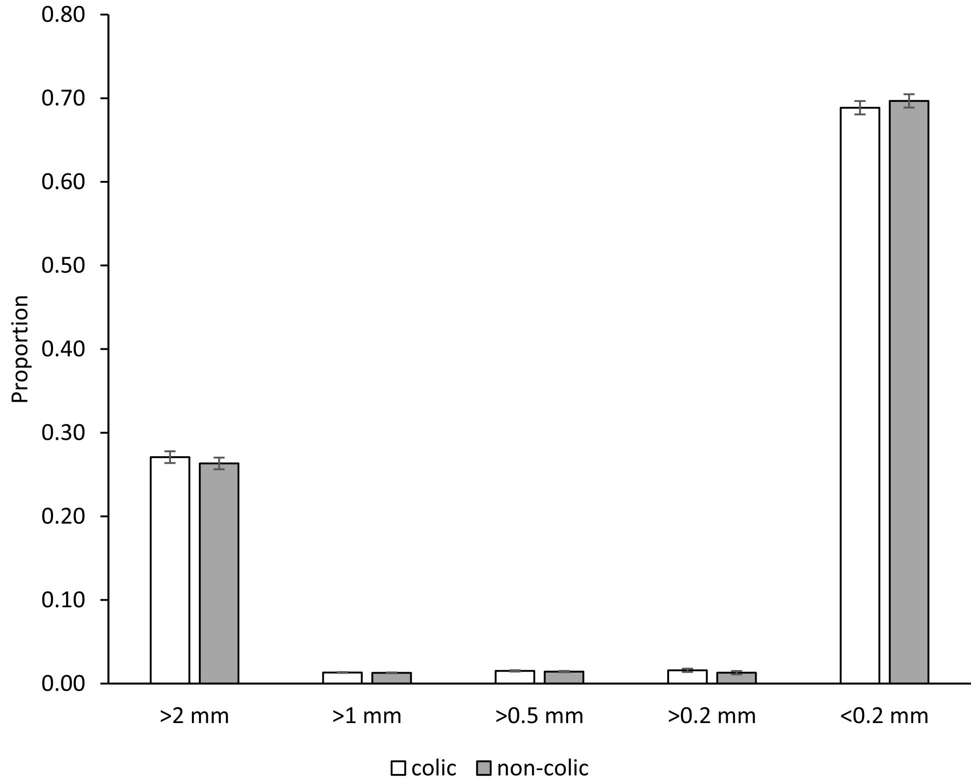

Fig. 1. Proportion of faecal particles of different size fractions in colic ($n = 67$) and non-colic ($n = 67$) horses ($P > 0.25$).

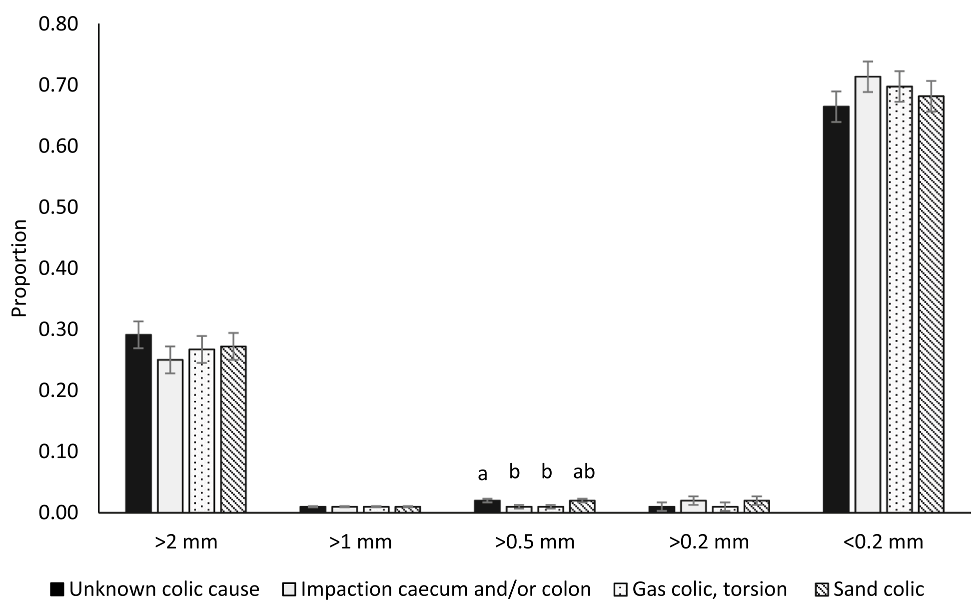

Fig. 2. Proportion of faecal particles of different size fractions in horses with different colic types (unknown colic cause n = 28, impaction caecum and/or colon $n = 18$, gas colic, torsion $n = 21$, sand colic n=7), $P > 0.11$ for all fractions except > 0.5 mm where $P = 0.004$. Different letters within particle size fraction represent difference between colic types.

impaction, and in horses with colon impaction the digesta has been described as dehydrated [7,8,26,27]. This may be a result of the large fluxes of fluid that takes place in the colon, especially in horses fed large concentrate meals, where high volumes of fluid are absorbed from the colon due to activation of the renin angiotensin-aldosterone system [27, 28]. At present, it is not known which role digesta DM concentration plays for the risk of colon impaction in horses. A drier, less fluid digesta is probably more prone to cause impactions, especially in the left colon [24]. It is noteworthy that the maximum faecal DM concentration in the current study was as high as 406 g per kg DM and it was present in a horse with colon impaction, while the lowest faecal DM concentration was 117 g per kg DM and was found in a non-colic horse. Average faecal DM concentration was however similar in horses with and without colic and between horses with different colic types and no colic. On the other hand, faecal DM may not reflect colonic DM; it has been reported to be both similar [21] and different from colonic DM concentration [22] in

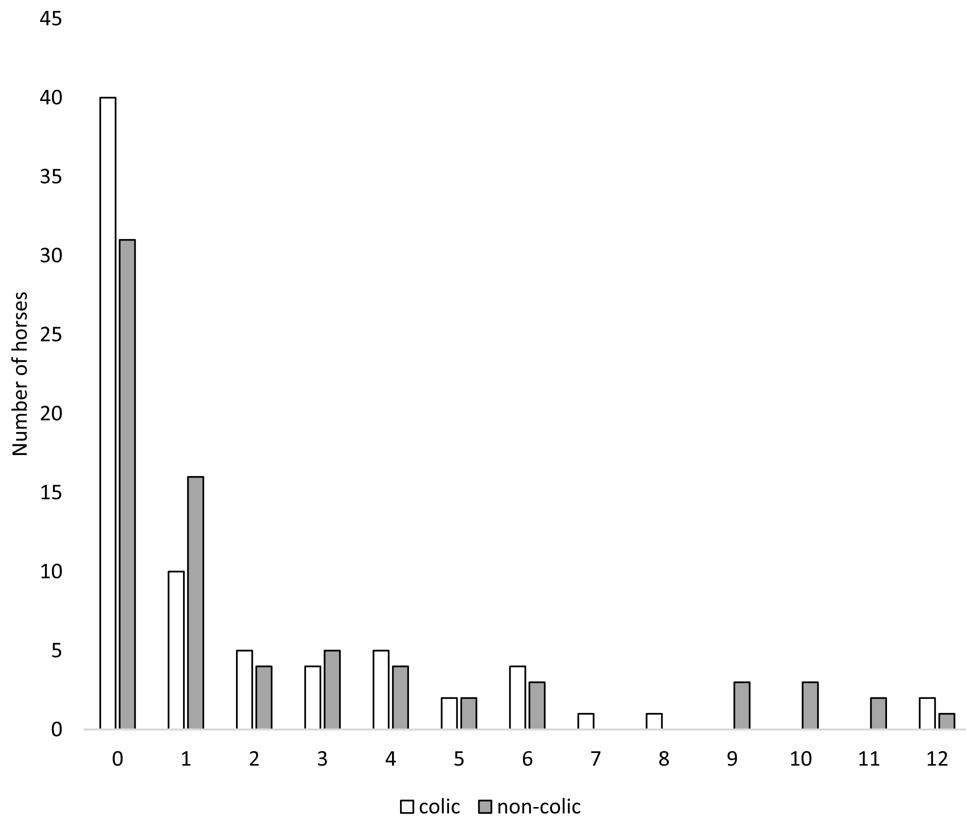

Fig. 3. Number of colic ($n = 67$) and non-colic horses ($n = 67$) with faecal sand score 0 (no presence of sand in faecal sample) to 12 (increasing amount of sand present in faecal sample, modified method after Husted *et al.*, 2005).

Table 3
Sand score in faeces in non-colic horses and horses with different types of colic ($N = 134$). Sand score according to a modified method after Husted et al. (2005).

Horse group	Sand score
Non-colic horses ($n = 67$)	2.4
Unknown colic type/cause ($n = 28$)	1.4
Impaction caecum and/or colon ($n = 18$)	2.3
Gas colic, torsion ($n = 21$)	1.5
Sand colic ($n = 7$)	2.7
P	0.57
SEM	1.07

non-colic horses. The use of faeces as a proxy sample for colon DM content may or may not be correct, and further studies on this are needed. In the current study, faecal samples were taken only once from each horse, and the representativeness of this sample to the general faecal dry matter content in the horse is unknown. To gain a better understanding of the variation in DM concentration in faeces, especially in colic horses, more samples per horse over a longer time period would be required. However, as the faecal samples were taken during an acute colic episode, they represent the faecal dry matter in that precise state, which was relevant to the aim of the study. About 2/3 of the colic horses had been examined for colic by a veterinarian prior to arrival at the hospital. It is not known if treatments prior to the referral to the hospital affected DM concentration in the faeces, and this is also a factor that should be included in future studies within the area.

Although the DM concentration of faeces did not differ between colic and non-colic horses in the current study, there may still be differences in the appearance of the faecal visual consistency. A dry appearance of faeces may be related to how the liquid is distributed in the solid matrix of faeces rather than to the DM concentration itself. This has been shown in horses with free faecal liquid (FFL), where liquid can be voided as a phase separate from the solids of faeces [10]. Horses with and without FFL were reported to have similar faecal DM concentration despite very different visual appearance of the faeces [10]. How the liquid is distributed in faeces is related to the water holding capacity of the solids, which is in turn influenced by fibre type, as different fibres vary in their hydrophilic properties [27,29,30]. Liquid distribution in the faecal matrix may also be influenced by particle size distribution, as smaller compared to larger particles have a larger surface area in relation to its mass, but it also depends on what the smaller particles consist of [31]. Data on the composition of particles of different size in equine faeces has not been found in the literature. However, in a study of fragmentation of forages during ruminant mastication, many smaller particles were found to have a high content of lignin [32]. Lignin has been reported to have a comparably low water holding capacity and low void space, both between and within lignin particles [31]. If smaller particles of equine digesta and/or faeces consist predominantly of lignin, the water holding capacity of this particle fraction may therefore be generally low. This could influence how easy the digesta flows within the gastro-intestinal tract, and perhaps increase the risk of impaction of fine particles. Lignin concentration may be comparably high in temperate grasses harvested in late plant maturity (*e.g.* [33]) and in specific grass species such as Coastal Bermuda grass (*Cynodon dactylon*) [34]. It has been reported that horses fed Coastal Bermuda grass hay had a higher risk of ileo-caecal impaction, compared to when fed other forages [35]. This is of interest as Coastal Bermuda grass, compared to other grass species, have been reported to show lower fibre digestibility and longer gastro-intestinal retention time in horses [34]. Other factors influencing water holding capacity are however also important, such as if the material has a fibrous or non-fibrous structure, its solubility and the proportion of hydrophilic sites [31]. Altogether, there is a need for a better understanding of how fibre composition and -quality of different feeds, fibre digestion in horses and gastro-intestinal passage rate of different feeds interact, and if there are associations to increased risk of impactions with certain feedstuffs. Another factor of interest for the risk of impactions and/or digesta flow is the viscosity of the liquid in the digesta, as it has been reported to be visually different in horses fed feed rations of various composition [19]. At present, knowledge of how the viscosity of digesta associates to digesta flow, digesta dry matter concentration and particle size distribution and the risk of impactions or other colic causes in horses is scant, and calls for further investigation.

4.3. Faecal particle size distribution

There were no general differences in faecal particle size distribution between colic and non-colic horses in the current study. Horses with unknown colic causes had a higher proportion of particles <1.0 but >0.5 mm compared to horses with colic due to impactions in caecum and/or colon, gas accumulation or torsion. The difference in proportion of this particle size fraction between the colic groups was however very small and most likely of no biological or clinical relevance. Presence of large particles (particle size not specified) in faeces has been described as a characteristic to evaluate in colic cases [7,8], and it has been suggested to indicate chewing difficulties in horses [8,36], as particle size in faeces has been reported to be similar to particle size in the stomach [37]. Mean faecal particle size have however been reported both to differ [38] and not to differ [39] before and after dental correction in horses, and mean faecal particle size and oral pathology was not associated in two other studies [14,40]. Horses with large colon impaction colic were reported to have similar dentition as non-colic horses in a hospital-based study [14], but mean faecal particle size was smaller in horses with large colon impaction colic (1.3 ±0.4 mm) compared to non-colic horses (1.7 ±0.4 mm) in the same study. In contrast, horses with large colon impaction showed a tendency to have a higher proportion of larger particles in their faeces compared to control horses [40]. A smaller mean faecal particle size in horses with colon impaction could result from an extended fibre degradation due to a longer retention time of the digesta in the hindgut during the impaction colic. This is however speculative, and it may also depend on the microbial activity and hindgut environment, as well as the composition of the smaller particles as discussed in Section 4.2. The impact of particle size on gastro-intestinal retention time in horses seems to be unclear. In horses without colic, the net retention time of differently sized digesta particles in the hindgut was reported to be similar [41]. In other studies, smaller compared to larger particles had longer retention times in the hindgut but it did not result in increased fibre degradation measured via fibre digestibility [42,43,44,45]. For a better understanding of associations between hindgut disturbances (such as impactions) and factors that influence gastro-intestinal transit time of digesta in different compartments of the gastro-intestinal tract, finding out the composition of faecal particles of different sizes may be helpful. In forages ground to pass sieves of different sizes, the concentration of neutral detergent fibre (NDF), acid detergent fibre (ADF), lignin and crude protein (CP) did not differ between the size fractions [46]. However, when each fraction was reground the digestion rates increased, indicating that reduced particle size through further grinding to finer particles can influence digestion rate [46]. If the same principle is valid also for equine hindgut digesta is currently not known.

In the current study, the majority of faecal particles were <0.2 mm in both colic and non-colic horses. This was both similar [9] and opposite [33,47] to results from studies where faecal particle size distribution has been reported in non-colic horses. In a study of one Swedish and one German horse population, both with/without FFL, faecal particle size distribution was found to differ with population, but not by presence/absence of FFL [10]. In another German study horses fed silage had a higher proportion of the smallest (smaller than 0.1 mm) and the largest (larger than 3.15 mm) particles compared to horses fed hay, where most of the particles were found to be of intermediate size [47]. As faecal particle size distribution can be influenced by factors such as the method used for determination of particle size, the individual horse, and the diet [15,48], it can be difficult to compare proportions of specific size fractions from different studies. Both wet and dry sieving can be used, but comparisons of the two methods have shown that dry sieving generally resulted in smaller particle size than wet sieving [15]. Dry sieving tended to fraction particles by diameter while wet sieving instead tended to separate particles by length [15,48,49]. Variation also occurs in sieve mesh size and number of sieves with different mesh sizes which naturally affect the resulting distribution of specific particle size fractions. In addition, sieving techniques are rough methods and modern image analysis methods may have better capabilities to detect differences in particle size distribution in faecal (and digesta) samples through *e.g.* higher resolution.

4.4. Sand in faecal samples

Sand sedimentation tests of faecal samples have been reviewed as methods to show sand accumulation in the intestines of horses [13]. Intestinal sand accumulation may cause sand colic in horses, but the reliability of sand sedimentation tests of faeces as an indicator of sand accumulation in the intestine is low, as horses with no signs of colic also have sand in their faeces [11,12,50]. This was confirmed in the current study, where 64 % of non-colic horses and 57 % of horses diagnosed with sand colic had presence of sand in their faeces. Radiography is a more reliable method than sand sedimentation tests of faeces to detect sand in the intestine of horses [50,51].

5. Conclusions

Faecal dry matter concentration did not differ between horses with or without colic, or between horses with different colic types. Faecal particle size distribution was similar among horses with or without colic. The proportion of particles >0.5 mm but <1.0 mm was higher in horses with unknown colic cause compared to colic due to caecum and/or colon impaction, gas accumulation or torsion, but the difference was miniscule and not considered to be of biological or clinical importance. Presence of sand in faeces was similar in horses with and without sand colic. From the results of this study, faecal dry matter concentration or particle size distribution were not promising as diagnostic tools for horses with colic. However, the composition of faecal particles of different size in colic and non-colic horses is largely unknown. Increased knowledge within this area may facilitate the understanding of digesta passage rate and the risk of colic (especially impactions) in horses.

Funding

The data and faecal samples in this study came from another study, which received funding from the Foundation for Swedish-Norwegian Equine Research (grant number H-15-47-097, grant recipient Eva Tydén). The funder had no impact on the design of the study, collection of samples, analyses, interpretation of data, writing the manuscript or in the decision to publish the results.

CRediT authorship contribution statement

Cecilia E. Müller: Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Anonymised data can be made available by the corresponding author.

Acknowledgements

MSc student Sandra Anne Englund is acknowledged for helping out with analyses of faecal samples in the project. Associate Professor Eva Tydén, Department of Animal Biosciences, Swedish University of Agricultural Sciences is gratefully acknowledged for providing access to faecal samples and data. Thanks also to all participating horse owners and clinicians at the Equine clinic at Evidensia Animal Hospital, Helsingborg, Sweden.

References

[1] Kaneene JB, Miller RA, Ross WA, Gallagher K, Marteniuk J, Rook J. Risk factors for colic in the Michigan (USA) equine population. Prev Vet Med 1997;30:23–36. and digesta retention time in the hindgut of horses. J Anim Sci 2014; 92: 1574-81.
[2] Tinker MK, White NA, Lessard P, Thatcher CD, Pelzer KD, Davis B, Carmel DK. Prospective study of equine colic risk factors. Equine Vet J 1997;29:454–8.
[3] Traub-Dargatz JL, Kopral CA, Seitzinger AH, Garber LP, Forde K, White NA. Estimate of the national incidence of and operation-level risk factors for colic among horses in the United States, spring 1998 to spring 1999. J Am Vet Med Ass 2001;219:67–71.
[4] Hillyer MH, Taylor FGR, Proudman CJ, Edwards GB, Smith JE, French NP. Case control study to identify risk factors for simple colonic obstruction and distension colic in horses. Equine Vet J 2002;34:455–63.
[5] Archer DC, Proudman CJ. Epidemiological clues to preventing colic. Vet J 2006; 172:29–39.
[6] Egenvall A, Penell J, Bonnett BN, Blix J, Pringle J. Demographics and costs of colic in Swedish horses. J Vet Intern Med 2008;22:1029–37.
[7] Goncalves S, Leblond A, Drogoul C, Julliand V. Using feces charactersitics as a criterion for the diagnosis of colic in the horse: a clinical review of 207 cases. Revue Méd Vét 2006;157:3–10.
[8] White II NA, A Desrochers. Alternative diagnostic techniques. In: Blikslager AT, White II NA, Moore JN, Mair TS, editors. The Equine Acute Abdomen, Third Edition. Hoboken, USA: John Wiley & Sons, Inc.; 2017. p. 266–70.
[9] Müller CE. Long stemmed vs. cut haylage in bales - Effects on fermentation, aerobic storage stability, equine eating behaviour and characteristics of equine faeces. Anim Feed Sci Technol 2009;152:307–21.
[10] Lindroth KL, Dicksved J, Vervuert I, Müller CE. Chemical composition and physical characteristics of faeces in horses with and without free faecal liquid – two case control studies. BMC Veterinary Res 2022;18:2.
[11] Husted L, Andersen MS, Borggaard OK, Houe H, Olsen SN. Risk factors for faecal sand excretion in Icelandic horses. Equine Vet J 2005;37:351–5.
[12] Landes AD, Hassel DM, Funk JD, Hill A. Fecal sand clearance is enhanced with a product combining probiotics, prebiotics, and psyllium in clinically normal horses. J Equine Vet Sci 2008;28:79–84.
[13] Niinistö K, Sykes BW. Diagnosis and management of sand enteropathy in the horse. Equine Vet Educ 2022;34:600–6.
[14] Gunnarsdottir H, Van der Stede Y, De Vlamynck C, Muurling F, De Clercq D, van Loon G, Vlaminck L. Hospital-based study of dental pathology and faecal particle size distribution in horses with large colon constipation. Vet J 2014;202:153–6.
[15] Udén P, Van Soest PJ. Comparative digestion of timothy (Phleum pratense) fibre by ruminants, equines and rabbits. Br J Nutr 1982;47:267–72.
[16] Curtis L, Burford JH, England GCW, Freeman SL. Risk factors for acute abdominal pain (colic) in the adult horse: a scoping review of risk factors, and a systematic review of the effect of management-related changes. PLoS ONE 2019;14(7): e0219307.
[17] Carmalt JL, Townsend HG, Janzen ED, Cymbaluk NF. Effect of dental floating on weight gain, body condition score, feed digestibility, and fecal particle size in pregnant mares. J Am Vet Med Assoc 2004;225:1889–93.
[18] Miyaji M, Ueda K, Hata H, Kondo S. Effects of quality and physical form of hay on mean retention time of digesta and total tract digestibility in horses. Anim Feed Sci Technol 2011;165:61–7.
[19] Lopes MAF, White II NA, MV Crisman, D Ward. Effects of feeding large amounts of grain on colonic contents and feces in horses. Am J Vet Res 2004;65:687–94.
[20] Zeyner A, Geißler C, Dittrich A. Effects of hay intake and feeding sequence on variables in faeces and faecal water (dry matter, pH value, organic acids, ammonia, buffering capacity) of horses. J Anim Physiol Anim Nutr 2004;88:7–19.
[21] Müller CE, von Rosen D, Udén P. Effect of forage conservation method on microbial flora and fermentation pattern in forage and in equine colon and faeces. Livest Sci 2008;119:116–28.
[22] Muhonen S, Philippeau C, Julliand V. Effects of differences in fibre composition and maturity of forage-based diets on the fluid balance, water-holding capacity and viscosity in equine caecum and colon digesta. Animals 2022;12:3340.
[23] Clauss M, Schiele K, Ortmann S, Fritz J, Codron D, Hummel J, Kienzle E. The effect of very low food intake on digestive physiology and forage digestibility in horses. J Anim Physiol Anim Nutr (Berl) 2014;98:107–18.
[24] Williams S, Horner J, Orton E, Green M, McCullen S, Mobasheri A, Freeman SL. Water intake, faecal output and intestinal motility in horses moved from pasture to a stabled management regime with controlled exercise. Equine Vet J 2015;47: 96–100.
[25] Williams S, Tucker CA, Green MJ, Freeman SL. Investigation of the effect of pasture and stable management on large intestinal motility in the horse, measured using transcutaneous ultrasonography. Equine Vet J 2011;43:93–7.
[26] White II NA, RM Dabareiner. Treatment of impaction colics. Vet Clin N Am Equine Practice 1997;13:243–59.
[27] Clarke LL, Roberts MC, Argenzio RA. Feeding and digestive problems in horses. Physiologic responses to a concentrated meal. Vet Clin North Am Equine Pract 1990;6:433–50.
[28] Blikslager AT. Colic prevention to avoid colic surgery: a surgeon's perspective (review article). J Equine Vet Sci 2019;76:1–5.
[29] Auffret A, Ralet MC, Guillon F, Barry JL, Thibault JF. Effect of grinding and experimental conditions on the measurement of hydration properties of dietary fibers. Food Sci Technol 1994;27:166–72.
[30] Jones SL, Spier SJ. Inflammatory diseases of the large intestine causing diarrhea. In: Reed SM, Bayly WM, editors. Equine internal medicine. Philadelphia: WB Saunders; 1998. p. 663–82. 1998.
[31] Boulos NN, Greenfield H, Wills RBH. Water holding capacity of selected soluble and insoluble dietary fibre. Int J Food Prop 2000;3:217–31.
[32] Pond KR, Ellis WC, Akin DE. Ingestive mastication and fragmentation of forages. J Anim Sci 1984;58:1567–74.
[33] Müller CE. Equine digestion of diets based on haylage harvested at different plant maturities. Anim Feed Sci Technol 2012;177:65–74.
[34] Hansen TL, Chizek EL, Zugay OK, Miller JM, Bobel JM, Chouinard JW, Adkin AM, Skurupey LA, Warren LK. Digestibility and retention time of coastal Bermudagrass (*Cynodon dactylon*) hay by horses. Animals 2019;9:1148.
[35] Little D, Blikslager AT. Factors associated with development of ileal impaction in horses with surgical colic: 78 cases (1986-2000). Equine Vet J 2002;34:464–8.
[36] Brosnahan MM, Paradis MR. Demographic and clinical characteristics of geriatric horses: 467 cases (1989-1999). J Am Vet Med Assoc 2003;223:93–8.
[37] Carmalt JL, Allen AL. The relationship between cheek tooth occlusal morphology, apparent digestibility and ingesta particle size reduction in horses. J Am Vet Med Assoc 2008;233:452–5.
[38] Di Filippo PA, Vieira V, Rondon DA, Quirino CR. Effect of dental correction on fecal fiber length in horses. J Equine Vet Sci 2018;64:77–80.
[39] Zwirglmaier S, Remler HP, Senckenberg E, Fritz J, Stelzer P, Kienzle E. Effect of dental correction on voluntary hay intake, apparent digestibility of feed and faecal particle size in horse. J Anim Physiol Anim Nutr 2013;97:72–9.
[40] Vlaminck L, De Vlamynck C, Muurling F, Van der Stede Y, De Boever J. Case control study to identify a possible relationship between dental pathology, impaction colic and faecal particle size distribution in horses: preliminary results. In: Proceedings of the 19th European Congress of Veterinary Dentistry; Nice, France; 2010. p. 91–4. 23-25 September 2010. European Veterinary Dental Society.
[41] Schwarm A, Clauss M, Ortmann S, Jensen RB. No size-dependent net particle retention in the hindgut of horses. J Anim Physiol Anim Nutr 2021;106:1356–63.
[42] Drogoul C, Tisserand JL, Poncet C. Feeding ground and pelleted hay rather than chopped hay to ponies 1. Consequences for in vivo digestibility and rate of passage of digesta. Anim Feed Sci Technol 2000;87:117–30.
[43] Drogoul C, Tisserand JL, Poncet C. Feeding ground and pelleted hay rather than chopped hay to ponies 2. Consequences on fibre degradation in the cecum and the colon. Anim Feed Sci Technol 2000;87:131–45.
[44] Van Weyenberg S, Sales J, Janssens GPJ. Passage rate of digesta through the equine gastrointestinal tract: A review. Livest Sci 2006;99:3–12.
[45] Miyaji M, Ueda K, Hata H, Kondo S. Effect of grass hay intake on fiber digestion and digesta retention time in the hindgut of horses. J Anim Sci 2014;92:1574–81.
[46] Cherney JH, Cherney DJR, Mertens DR. Fiber composition and digestion kinetics in grass stem internodes as influenced by particle size. J Dairy Sci 1988;71:2112–22.
[47] Müller G. Feldstudie Zur Versorgung Mit Nährstoffen Und Zu Einflussfaktoren Auf Die Kotzusammensetzung Bei Pferden Unter Fütterung Von Grassilage Oder Heu Als Rauhfutter. Doctoral Dissertation B727712. Germany: Tierärztliche Hochschule Hannover; 2002. p. 63–5.
[48] Udén P. The determination of digesta particle size in some herbivores. Anim Feed Sci Technol 1982;7:35–44.
[49] Ulyatt MJ, Dellow DW, Reid CSW, Bauchop T. Structure and function of the large intestine of ruminants. In: McDonald IW, Warner ACI, editors. Digestion and metabolism in the ruminant. Int. Symp. Ruminant physiol. Univ. New england publ. Unit. Australia: Armidale, New South Wales; 1975. p. 1119–33.
[50] Kendall A, Ley C, Egenvall A, Bröjer J. Radiographic parameters for diagnosing sand colic in horses. Acta Vet Scand 2008;50:17.
[51] Niinistö KE, Määttä MA, Ruohoniemi MO, Paulaniemi M, Raekallio MR. Owner-reported clinical signs and management-related factors in horses radiographed for intestinal sand accumulation. J Equine Vet Sci 2019;80:10–5.