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ORIGINAL RESEARCH

A single-centre retrospective study of surgical site infection following equine colic surgery (2013–2021)

Theunis Steyn Griessel[1] | **Juan Alberto Muñoz Morán**[2] | **Charles Byaruhanga**[3] | **Yolandi Smit**[1]

[1]Department of Companion Animal Clinical Studies, Faculty of Veterinary Science, University of Pretoria, Onderstepoort, South Africa

[2]Hospital Veterinario Sierra de Madrid, San Agustin de Guadalix, Madrid, Spain

[3]Department of Veterinary and Tropical Diseases, Faculty of Veterinary Science, University of Pretoria, Onderstepoort, South Africa

Correspondence
Theunis Steyn Griessel, Onderstepoort Veterinary Academic Hospital, Faculty of Veterinary Science, University of Pretoria, Onderstepoort, South Africa.
Email: theunisgr@gmail.com

Present address: Theunis Steyn Griessel, Onderstepoort Veterinary Academic Hospital, Faculty of Veterinary Science, University of Pretoria, Onderstepoort, South Africa

Abstract

Background: Surgical site infection (SSI) is a significant cause of postoperative morbidity following equine laparotomy. Therefore, if risk factors for SSI can be identified, morbidity may consequently be reduced. The objectives of this study were to determine the prevalence of SSI in horses undergoing exploratory laparotomy at a single hospital over an 8-year period (2013–2021), investigate the risk factors associated with SSI and report on the bacterial isolates identified.

Methods: The medical records of horses that had an exploratory laparotomy performed at the teaching hospital due to colic were retrospectively reviewed. SSI was defined as any purulent or serous discharge from the laparotomy incision for more than 24 hours duration during hospitalisation. Pre-, intra- and postoperative risk factors for SSI were identified using multivariable logistic regression analysis.

Results: A total of 143 horses met the criteria for inclusion in the study, of which 38 developed an SSI (26.6%, 95% confidence interval: 19.5–34.6%). Multivariable analysis revealed that the application of a postoperative abdominal bandage was significantly associated with a decreased likelihood of SSI (odds ratio = 0.29, $p = 0.026$).

Limitations: As this was a retrospective study performed at a single hospital, the findings may have limited generalisability.

Conclusions: The application of a postoperative abdominal bandage is protective against SSI in horses following exploratory laparotomy for colic.

KEYWORDS
colic, equine, exploratory laparotomy, risk factors, surgical site infection

INTRODUCTION

Colic is a common cause of death in the general horse population.[1–3] Most colic episodes will resolve with medical therapy; however, around 9% of colic cases require either surgical intervention or euthanasia.[4,5] Following colic surgery, current survival to discharge, excluding anaesthetic-related deaths, is reported to range from 74% to 85%.[6,7] Of the horses that survive to discharge, 63–85% return to their previous athletic performance.[8,9] However, postoperative complications following colic surgery are common.[10] Not only do they negatively impact the likelihood to return to athletic use and survival, they can also contribute to an increased duration and cost of hospitalisation.[11–14]

Surgical site infection (SSI) is a frequently reported complication following exploratory laparotomy for colic in horses. The reported prevalence of SSI varies between 7.4% and 43% at equine referral centres worldwide.[15–17] This broad range has been attributed to the differences in the definition of SSI used in some previous studies.[18–20] The incidence of SSI in horses is far greater when compared to people (13.3%), cattle (12.8%) and small animals (5.5%).[21–23] Abdominal incisional SSI in horses is also more likely to lead to the development of incisional hernia formation following exploratory laparotomy.[24]

Multiple studies have identified potential risk factors associated with SSI following exploratory laparotomy for colic. These risk factors have been categorised into pre-, intra- and postoperative factors. The risk factors identified include breed,[25, 26] age,[25, 27] elevated packed cell volume (PCV; >48%),[28] elevated heart rate (>60 beats/min), severity of colic signs,[29] season,[28] increased body mass index,[30] surgeon experience,[31] greater incisional length (>27 cm),[26] reduced intraoperative partial pressure of oxygen (<80 mmHg), greater anaesthetic time (>2 hours duration),[32] incisional closure method,[28, 29, 33–36] surgical procedure,[28] no postoperative abdominal bandage,[29] postoperative colic[26, 28, 37, 38] and pyrexia.[27, 29]

The objectives of this study were (1) to determine the prevalence of SSI in horses following exploratory laparotomy for colic at a teaching single hospital; (2) to determine pre-, intra- and postoperative risk factors for SSI following exploratory laparotomy for colic; (3) to determine the association between SSI and hernia formation following an exploratory laparotomy for colic; and (4) to report on bacterial isolates cultured from incisional drainage during hospitalisation.

MATERIALS AND METHODS

Study design and case selection

The medical records of horses that had an exploratory laparotomy performed due to colic at the Onderstepoort Veterinary Academic Hospital, University of Pretoria, between 2013 and 2021 were retrospectively reviewed. The outcomes of interest for this study were the development of SSI during hospitalisation following exploratory laparotomy for colic, identification of risk factors and the identification of bacterial isolates cultured from the SSI.

SSI was defined as any purulent or serous discharge from the laparotomy incision for more than 24 hours duration during hospitalisation. Horses that did not survive to discharge were included in this study, but horses that underwent repeat laparotomy within 4 weeks of the first exploratory laparotomy were excluded. All horses included in the study received standard postoperative medical therapy consisting of flunixin meglumine for a minimum of 48 hours (Finadyne, MSD Animal Health, 50 mg/mL IV at 1.1 mg/kg every 12 hours), penicillin (Depocillin, MSD Animal Health, IM at 22,000 IU/kg every 12 hours) and gentamicin (Genta 50 Phenix, Virbac, 50 mg/mL IV at 6.6 mg/kg every 24 hours). The duration of antibiotics was dependent on regular reassessment of the white blood cell (WBC) count and white cell morphology via blood smear. Postoperative antimicrobials were discontinued when the WBC was within the normal reference range (4.7–11 × 10^9 cells/L) and white cell morphology had normalised.

A standard protocol for postoperative incisional protection was performed. All horses had a stent bandage placed over the incision for recovery. This remained in place for 12–24 hours or was removed immediately after recovery if it had become soiled or dislodged. Following removal of the stent, either an abdominal bandage or no incisional protection was placed, according to the clinician's preference. The abdominal bandages consisted of sterile Gamgee roll, self-adherent wrap (Coban; 3M) and an adhesive support bandage (Tensoplast; BSN Medical). Abdominal bandages were monitored closely for any slippage and were replaced every other day until the horse was discharged. During bandage changes, incisions were closely inspected for any signs of drainage. Horses without a bandage had their incisions inspected daily until they were discharged from the hospital.

Data for various pre-, intra- and postoperative variables considered possible risk factors for SSI were extracted from the horses' medical records. The preoperative variables recorded at admission included bodyweight, breed, age, sex, clinical parameters, PCV, total serum protein (TSP), peripheral lactate and if surgery was performed out of hours. In addition, the month of admission was recorded and categorised according to season: autumn (March–May), winter (June–August), spring (September–November) and summer (December–February).

Variables recorded intraoperatively included duration of anaesthesia and surgery, surgeon qualification, lesion description (location and strangulating/non-strangulating), if a small intestinal resection was performed, the location of anastomosis, if an enterotomy was performed, type of suture material used for linea closure and whether a repeat laparotomy was performed.

Variables recorded postoperatively included heart rate 24 hours after surgery, PCV 24 hours after surgery, TSP 24 hours after surgery, antimicrobial type and duration, development of postoperative colic (defined as clinical signs of abdominal pain necessitating additional analgesia), postoperative ileus (defined as >2 L net reflux obtained on at least two occasions), pyrexia (defined as a rectal temperature >38.5°C), when SSI was first identified, duration of hospitalisation, whether postoperative incisional protection was provided and whether the horse survived to discharge.

If discharge was noted from the incisional site for more than 24 hours following surgery, an area on the incision was prepared in a sterile manner and a swab was taken for bacterial culture. The results for samples submitted for aerobic and anaerobic cultures and antibiograms were recorded. Telephone interviews with the horse owners were performed 6 months after the last data collection (July 2021) to request follow-up information regarding the prevalence of herniation following discharge.

Data analysis

Descriptive statistics were used to summarise the data. The prevalence and binomial exact 95% confidence interval were calculated for SSI. A multiple imputation approach was applied to account for missing data; this generated plausible values by predicting missingness and missing values through regression models. The functional form of relationships between continuous variables and the log-odds of SSI were tested using a generalised additive model and smoother scatter plots.[39] This was to establish if a variable had a significant non-linear relationship, which was a criterion for categorising a variable following biologically plausible values.

Univariate association between each predictor variable and the occurrence of SSI (binary outcome: no/yes) was assessed using univariate generalised linear models for categorical and continuous variables. Variables with a *p*-value of 0.05 or less in the univariate analysis were assessed for multicollinearity using Cramer's *V*-test and the variance inflation factor (VIF). Collinearity was present if Cramer's *V* was greater than 0.6 or the VIF was greater than 4, and if so, then a biologically more plausible variable with regards to SSI was selected. The retained variables were combined in multivariable binomial generalised linear models that employed a forward elimination approach to determine risk factors for SSI. Variables were assessed in different multivariable models, and the criterion for retention was if inclusion of a variable resulted in a likelihood ratio test *p*-value of less than 0.05 and the Hosmer–Lemeshow test statistic showed a good fit of the data to the model. We also tested for significance of interactions between pairs of biologically plausible retained variables. All data analysis was performed using R software (version 4.3.2) at a 5% level of significance.

RESULTS

Prevalence of surgical site infection

Of the 143 horses that met the inclusion criteria for the study, 38 (26.6%, 95% confidence interval: 19.5–34.6%) developed an SSI, and of these, only three (7.9%) did not survive to discharge. Of the 105 horses that did not develop an SSI, 22 (21.0%) did not survive to discharge. Horses were hospitalised for a mean of 12.3 days (standard deviation [SD] 9.1).

Univariate analysis for surgical site infection

Descriptive and univariate statistics for the categorical and continuous variables analysed are shown in Tables S1 and S2, respectively. Of the 32 initially evaluated explanatory variables, only three (postoperative surgical site protection, postoperative antimicrobials and postoperative pyrexia) were significantly associated ($p \leq 0.05$) with SSI in the univariate analysis (Table S1). The estimated relationships between the likelihood of SSI and the various continuous variables are shown in Figure S1. There was no collinearity between the variables. There was a significant association between development of SSI and development of pyrexia postoperatively. However, pyrexia was not included in the multivariable analysis as it was considered a confounder, due to the fact that it can be the result of SSI. Therefore, two variables (postoperative surgical site protection and postoperative antimicrobials) were assessed in the multivariable logistic regression models, and after a forward stepwise elimination procedure, the final model was built on both.

Multivariable analysis for surgical site infection

The results of the final logistic regression model are shown in Table 1. Application of a postoperative abdominal bandage was significantly associated with a decreased likelihood of SSI, while administration of a combination of penicillin, gentamicin and metronidazole during the postoperative period was associated with an increased risk of SSI development compared with administration of penicillin and gentamicin only. There were no outliers in the data set, and the Hosmer–Lemeshow test showed a good fit of the final model to the data ($\chi^2 = 0.12$, $p = 0.79$).

Surgical site infection and bacterial culture

SSI was identified a mean of 9.5 days (SD 7.1) postoperatively. Only 24 horses had cultures performed on the incisional drainage, all of which had a positive bacterial culture result. Bacterial isolates identified were *Escherichia coli* (37.8%), *Staphylococcus* spp. (24.3%), *Enterococcus* spp. (24.3%), *Pseudomonas* spp. (16.2%), *Salmonella* spp. (16.2%), *Enterobacter* spp. (10.7%), *Klebsiella pneumonia* (10.7%), multidrug-resistant *Staphylococcus aureus* (5.4%), *Morganella morgani* (5.4%), *Streptococcus zooepidemicus* (2.7%), *Enterobacillus cloaca* (2.7%), multidrug-resistant *Enterococcus faecalis* (2.7%), *Acinetobacter baumanni* (2.7%), *Pantoea* spp. (2.7%) and *Bacteroides fragilis* (2.7%).

Association between hernia formation and surgical site infection

The association between hernia formation and SSI was assessed for the 97 horses that had complete follow-up records. It was found that hernia formation was 7.17 times more likely to occur in horses with SSI (58.06%) than in horses with no SSI (15.15%) ($p < 0.001$).

DISCUSSION

In this study, the prevalence of SSI following exploratory laparotomy was found to be 26.6%. This is comparable to the prevalence previously reported in the literature.[28,31,37,38] However, there is considerable variation regarding the definition used

TABLE 1 Multivariable analysis of factors associated with surgical site infection following exploratory laparotomy in cases of colic in horses

Variable	Coefficient	Standard error	Odds ratio	95% CI of odds ratio	Wald *p*-value	Likelihood ratio test *p*-value
Postoperative antimicrobials						
Penicillin and gentamicin	Ref.					
Penicillin, gentamicin and metronidazole	1.108	0.404	3.03	1.37–6.68	0.006	0.005
Postoperative surgical site protection						
No	Ref.					
Abdominal bandage	−1.209	0.529	0.29	0.11–0.84	0.022	0.026

Abbreviations: CI, confidence interval; Ref., reference category.

for SSI following exploratory laparotomy in horses. Certain studies simply define SSI as a purulent discharge from the incision,[40, 41] whereas other studies have defined it as any type of incisional drainage, irrespective of the character, with a positive bacterial culture from the incisional site.[31, 42–45] This results in a relatively wide range in the prevalence of SSI reported and makes it difficult to accurately compare these studies. The definition for SSI used in this study is similar to that used by Isgren et al.,[28] where the reported prevalence of SSI was 25.4%. Other studies, where a more stringent definition was used, have reported a lower prevalence.[26] Studies have also reported on the development of SSI following discharge.[20, 26, 29] In the present study, no immediate follow-up was performed on horses that were discharged, which could have led to disparity in the prevalence of SSI reported.

Of the possible risk factors assessed in the univariate analysis, postoperative pyrexia, postoperative antimicrobials and postoperative surgical site protection were identified to be statistically significantly associated with SSI. Freeman et al.[45] found that 85% of colic patients developed a mild pyrexia postoperatively and that it was not necessarily associated with infection. However, horses that developed a higher rectal temperature (>39.2°C), those that developed pyrexia for a longer duration and those that developed pyrexia at a later stage after the surgery were more likely to suffer from a postoperative infection. Other studies have also shown the positive association between the occurrence and duration of pyrexia and the risk of developing SSI following colic surgery.[27, 29] Therefore, even though a slightly elevated rectal temperature may be normal in the postoperative colic horse, these horses should still be examined closely for other signs of infection.[38] Smith et al.[29] also found a positive association between pyrexia and the development of SSI in the follow-up period, emphasising the importance of monitoring postoperative colic horses for the development of SSI following discharge.

With the global increase in multidrug-resistant bacteria, responsible use of antimicrobials is paramount. Multiple studies have shown that decreasing the duration of antimicrobials does not have an effect on the development of SSI following exploratory laparotomy.[45, 46] In the present study, the use of penicillin, gentamicin and metronidazole was found to be associated with a greater risk of SSI development when compared to the use of penicillin and gentamicin only. However, the duration of antimicrobials was not found to be a significant risk factor for the development of SSI, which is in line with what has previously been reported in the literature. On review of these cases, it was found that horses were administered metronidazole if they had secondary postoperative complications such as pneumonia. Romatowski's study found that infections distant to the incision were associated with an increased frequency of incisional infections.[47] Thus, horses that develop secondary postoperative infections should also be closely monitored for signs of SSI development.

This study found that application of an abdominal bandage was significantly associated with a decreased likelihood of SSI. However, there is significant disagreement in the literature regarding this subject. Some studies have shown beneficial effects of providing postoperative incisional site protection,[29, 44] while other studies suggest that incisional site protection might act as a source of contamination and increase the likelihood of SSI development.[41] Ingle-Fehr et al.[42] suggested that oedema around the incisional site may affect the blood supply to the surrounding tissue, resulting in poorer wound healing and depression of the local immune system, and therefore providing an ideal environment for growth of bacteria. It is the opinion of the authors of the present paper that horses that received an abdominal bandage postoperatively subjectively developed less postoperative oedema around the incision site. The conflicting results presented in the literature may indicate that the exact method and duration of postoperative incisional protection may be critical when trying to prevent SSI following colic surgery. Future studies may benefit from standardising incisional protection methods and the materials used to investigate the ideal technique for providing incisional support and protection against contamination. How often dressings are changed, who does the dressing changes and where the dressing changes are done (in the stable or in a clean work-up area) may be important factors to consider.

A tentative diagnosis of SSI can be made based on clinical signs such as pyrexia, incisional site swelling, pain and discharge from the laparotomy site.[15, 28] In the present study, SSI was identified on average 9.5 days postoperatively and resulted in horses being hospitalised for 10 days longer than horses without SSI. This is similar to previous studies and emphasises the importance of early recognition and treatment of SSI to reduce the financial impact of the morbidity. Ultrasonographic examination of the incisional site has been shown to be useful in the early stages of infection due to its high sensitivity and specificity, and thus should be considered to assist in the early diagnosis and monitoring of SSI.[15]

We found that incisional hernia formation was 7.17 times more likely to occur in horses that developed SSI following colic surgery, which correlates with what has been found in previous studies.[48, 49] This finding emphasises the importance of early recognition of SSI and the need to initiate early management strategies to prevent incisional separation to possibly reduce the final size of the hernia.[48, 50] Other risk factors for incisional hernia formation have been identified. An elevated heart rate and signs of endotoxaemia on admission have been shown to be risk factors for incisional hernia development.[16, 24] Postoperative colic, resulting in excessive tension on the incision, has also been shown to be a risk factor for hernia development.[24] Multiple studies have shown that a repeat laparotomy is associated with a significantly increased risk of SSI and incisional hernia formation.[51–53] This is an important consideration as the development of a ventral midline incisional hernia has a significant effect on the perceived value of the horse. The poor aesthetic appearance of an incisional site hernia, the high costs involved in surgical repair and the perception that an abdominal wall defect could render a horse unfit for athletic activities may be contributing factors.[8] A major limitation to these data is that hernia formation was only identified by owners noticing a defect in the abdominal wall; therefore, horses that may have developed linea alba defects without subsequent visual deformation were not included.

CONCLUSION

SSI following colic surgery is a complex, multifactorial process. This study identified postoperative pyrexia and the type of postoperative antimicrobials administered to be risk factors in the development of SSI. Meanwhile, postoperative surgical site protection was found to be protective against SSI following colic surgery. In the majority of SSI cases, *E. coli*, *Staphylococcus* spp. and *Enterococcus* spp. were cultured from incisional drainage. The risk factors identified in this study contribute to current knowledge on SSI in postoperative colic horses and may be used to guide clinical decision making.

AUTHOR CONTRIBUTIONS

Theunis Steyn Griessel, Juan Alberto Muñoz Morán and Yolandi Smit conceived and designed the study. Theunis Steyn Griessel was the primary researcher and involved in the data collection and analysis. Charles Byaruhanga provided statistical guidance and performed data analysis. All authors contributed to the revision of the article and approved the final version.

CONFLICT OF INTEREST STATEMENT

The authors declare they have no conflicts of interest.

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DATA AVAILABILITY STATEMENT

The data collected for this paper will be made available by the corresponding author upon reasonable request.

ETHICS STATEMENT

Research ethic approval was obtained from the Research Ethics Committee, Faculty of Veterinary Science, University of Pretoria (reference number: REC 165-20).

ORCID

Theunis Steyn Griessel https://orcid.org/0009-0009-3177-4539

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SUPPORTING INFORMATION

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

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