Ex vivo comparison of barbed and unbarbed sutures for the closure of caecal and pelvic flexure enterotomies in horses

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Summary
In this study the caecum and large colon were harvested from 24 slaughtered horses. On each sample, an 8-cm long enterotomy was performed. Enterotomies were closed using either barbed or unbarbed glycomer-631. We compared the time to close, appearance, length of suture material, bursting pressure, and costs associated with each type of material. Our findings demonstrated that time to close was significantly shorter (caecum, $P = 0.034$; pelvic flexure, $P = 0.039$) using barbed sutures (caecum 610.4 seconds; pelvic flexure 699.3 seconds) than unbarbed sutures (caecum 661.0 seconds, pelvic flexure 743.1 seconds). The length of suture material used was significantly less (caecum, $P < 0.0001$; pelvic flexure, $P < 0.0001$) with barbed (caecum 28.1 cm, pelvic flexure 32.0 cm,) compared with unbarbed sutures (caecum 41.6 cm; pelvic flexure 46.6 cm). There were no significant differences in bursting pressure (caecum, $P = 0.294$; pelvic flexure, $P = 0.430$) between barbed (caecum, 172.5 mmHg, pelvic flexure, 188.9 mmHg) and unbarbed sutures (caecum 178.3 mmHg, pelvic flexure 183.3 mmHg). The cost was higher using barbed sutures. However, the use of barbed sutures was faster, left less suture material in the tissue, and sustained comparable bursting pressure to unbarbed sutures. We therefore conclude that barbed sutures are a valid alternative to unbarbed sutures for closing large intestine enterotomy in horses.

Comparazione ex vivo di suture con o senza dentatura per la chiusura delle entorotomie nelle flessure pelviche e dell'intestino cieco nei cavalli

Parole chiave
Sutura dentata,
Pressione di scoppio,
Cieco,
Colon,
Chiusura di enterotomia,
Cavallo,
Chirurgia,
Flessura pelvica,
Sutura non dentata.

Riassunto
In questo studio sono stati raccolti l'intestino cieco e quello crasso da 24 cavalli macellati; per ogni campione è stata eseguita un'enterotomia di 8 cm suturata con tecnica dentata o usando glycomer-631. Sono stati confrontati la cicatrizzazione, l'aspetto, la lunghezza del materiale, la pressione di rottura e i costi associati a ciascun tipo di materiale. Il tempo di cicatrizzazione è stato significativamente più breve (cieco $P = 0{,}034$, flessione pelvica $P = 0{,}039$) con le suture dentate (cieco 610,4 secondi, flessione pelvica 699,3 secondi) rispetto a quelle non dentate (cieco 661,0 secondi, flessione pelvica 743,1 secondi). La lunghezza del materiale di sutura si è dimostrato essere significativamente inferiore (cieco $P < 0{,}0001$, flessione pelvica $P < 0{,}0001$) nelle prime (cieco 28,1 cm, flessione pelvica 32,0 cm) rispetto alle seconde (cieco 41,6 cm, flessione pelvica 46,6 cm) mentre non ci sono state differenze significative (cieco $P = 0{,}294$, flessione pelvica $P = 0{,}430$) nella pressione di rottura (suture dentate: cieco 172,5 mmHg, flessione pelvica 188,9 mmHg; non dentate: cieco 178,3 mmHg, flessione pelvica 183,3 mmHg). L'uso di suture dentate ha un costo maggiore ma è più veloce, lascia meno materiale di sutura nel tessuto e sostiene una pressione di rottura paragonabile alle suture non dentate; sono dunque una valida alternativa per la chiusura dell'enterotomia dell'intestino crasso nei cavalli.

Introduction

Enterotomy procedures are performed in the large intestine during equine surgery, and various closure techniques have been described *in vivo* and *in vitro* (Johnston *et al.* 1997, Rosser *et al.* 2012, Gandini *et al.* 2013, Rakestraw *et al.* 2012). Successful enterotomy closure techniques involve ensuring watertight tissue approximation, maintaining luminal diameter, withstanding increasing intraluminal pressures, and limiting the amount of exposed suture material. The hand-sewn, 2-layer suture technique is favoured for use in the caecum (Rakestraw *et al.* 2012) and large colon (Gandini *et al.* 2013, Rakestraw *et al.* 2012).

A new barbed suture material was recently made available to surgeons. Barbed suture material is characterised by the presence of a welded loop at one end and barbs cut into the body of the thread distributed circumferentially along the thread. This produces a suture material that does not require the tying of a knot at the start or end of the suture line. This, in turn, reduces the amount of suture material that is exposed, and improves the strength of the suture line by eliminating the need for knots, which are otherwise considered the weakest portion of a suture line. In addition, the shear stress is distributed along the entire length of the suture (Zaho *et al.* 2013). While it was initially intended for human plastic surgery (Ruff 2006, Ruff 2013), barbed suture has proven effective in other fields such as orthopedics, gynecology (Maheshwari *et al.* 2015, Medina *et al.* 2014, Manoucheri *et al.* 2013, Chamsy *et al.* 2013, Greenberg 2010), and gastrointestinal surgery for performing end-to-end anastomosis and closing enterotomies in dogs (Hansen *et al.* 2012, Ehrhart *et al.* 2013, Omotosho *et al.* 2011, Miller *et al.* 2012), pigs (Demyttenaere *et al.* 2009), and humans (Nemecek *et al.* 2013, Tyner *et al.* 2013). To date, 4 reports have been published on the use of barbed sutures in horses for intestinal anastomosis and laparoscopic procedures (Nelson *et al.* 2014, Ragle *et al.* 2013, Albanese 2013). Our hypothesis is that barbed suture could prove to be a valuable option for enterotomy site closure in horses, and could favourably compare with unbarbed suture material used for the same purpose.

The aim of this study was to compare barbed suture with conventional (unbarbed) suture materials for enterotomy closure in horses. The following items were compared: construction time, amount of suture material used, macroscopic appearance, bursting pressure, mode of failure, and cost.

Materials and methods

Intestinal specimens

Intestinal samples from the large colon, including the pelvic flexure as well as the caecum in its entirety, were harvested at a local abattoir from 24 slaughtered horses. Horses were aged 12-18 months, with no apparent gastrointestinal disease. Specimens were stored in Lactated Ringer's solution at 4 °C before testing. The enterotomy closures and testing were completed within 6 hours of the death of the horse.

Samples were randomly assigned into 1 of 2 groups (unbarbed or barbed) by means of a random numbers generator[1].

The caecum and the pelvic flexure of the 24 horses were randomly assigned to 1 of 2 groups. In the unbarbed group, a hand-sewn technique with glycomer 631 (Glycomer 631, Biosyn, Covidien Italia, Segrate Milano, Italy) was used to close the enterotomy site. In the barbed group, the same technique was applied, but barbed glycomer 631 (Barbed glycomer 631, VLoc-90, Covidien Italia, Segrate Milano, Italy) was used.

The same surgeon (MG) and assistant (GG), performed all of the procedures while the intestines were lying on a table (caecum) or a colon tray (pelvic flexure).

Procedures

On all specimens an 8-centimetre-long enterotomy was performed on the caecal apex between the lateral and ventral bands and on the pelvic flexure on the antimesenteric side. Specimens were closed using a hand-sewn double-layer technique (Gandini *et al.* 2013, Rakestraw *et al.* 2012) that included a full thickness, simple continuous suture pattern over-sewn with a Cushing pattern. The suture bite size was approximately 3 mm from the incision edge, and 5 mm in length.

In the enterotomies for the unbarbed group, the suture was tied and cut after the first layer. The second layer was performed with a new strand of the same suture material. All knots were buried in the second suture layer.

In the enterotomies for the barbed group, the suture was started by passing the needle through the welded loop of the suture thread. When the first layer was completed, the pattern was continued for 2 passages, exceeding the end of the length of the enterotomy by approximately 10 mm. The second layer was completed with a second strand of the same suture material. Again, after the second layer was completed, the suture was finished by taking 2 additional bites that exceeded the length of the enterotomy.

[1] www.random.org.

Macroscopic appearance and exposed suture material

After completion, all enterotomies were evaluated for differences in serosal appearance and the presence of exposed suture material.

Construction time

Time (in seconds) of enterotomy closure was defined as the time from the first suture bite to the cutting of the excess suture thread.

Length of suture material

The initial length of the suture strand was measured with a digital caliper, just after opening the package. The length of suture material used to complete the closure was measured by subtracting the residual length of the suture at the end of the procedure from the initial length. In the barbed group enterotomies, only the material trimmed after completion of the suture was measured, while in the unbarbed group enterotomies, the suture material trimmed from the initial knot was also measured.

Bursting pressure

The bursting strength of each specimen was determined by specimen inflation using a previously described water immersion test (Gandini *et al.* 2006). Briefly, a cannula connected to a compressed air tank was inserted into the lumen, and a similar cannula, connected to a calibrated mercury sphygmomanometer, was inserted at the other end (or at the same end in the caecal enterotomy samples). The intestine was submerged in water, and the lumen was inflated with air (1 L/min). Luminal pressures were measured continuously, and were video-recorded to determine the peak pressure at which each specimen failed or leaked. This was detected by the presence of air bubbles in the water and a drop in pressure measured by the sphygmomanometer.

Mode of failure

Mode of failure was defined by the location at which the construct failed during bursting pressure testing. We identified 3 possible modes of failure relative to the suture line: (1) Failure at the knot (knot slippage) for unbarbed suture, (2) failure at the suture (suture breaking), and (3) failure at the tissue (tearing of the tissue). The following were also noted: failure at the tissue and tearing at the enterotomy site, tearing adjacent to the enterotomy, or tearing at a distant location.

Cost

The cost for each enterotomy in euros was calculated according to pricing from a local surgical supply distributor and the number of strands used in each procedure.

Statistical analysis

Normality of the data was evaluated using the Shapiro-Wilk normality test. For caecal enterotomies, a Mann-Whitney test was employed to compare the data that had non-normal distributions (construction time and bursting pressure) while an unpaired t-test with a Welch correction applied for unequal variances was employed to test the length of the suture material that was used. For pelvic flexure enterotomies, an unpaired t-test with Welch's correction applied for unequal variances was used to compare all variables. All statistical analyses were performed with commercially available software (GraphPad Prism 6, GraphPad Software, San Diego, CA), with significance set at $P < 0.05$.

Results

Results are summarised in Table I.

Macroscopic appearance and exposed suture material

All enterotomies had a similar appearance macroscopically, with a smooth inverted surface. In many specimens in the unbarbed group, there was some exposed suture material where the last knot was tied (8 of 12 in the caecum and 10 of 12 in the large colon), while no exposed suture material was evident in the barbed group.

Table I. *Construction time, length of suture material and bursting pressure of intestinal enterotomies closed with barbed or unbarbed suture material.*

		Construction time (sec)	95% CI interval	Length of suture material (cm)	95% CI interval	Bursting pressure (mmHg)	95% CI interval
Caecum	Unbarbed (mean)	661.0	629.0-693.0	41.6	40.7-42.51	178.3	167.4-189.3
	Barbed (mean)	610.4*	575.7-643.5	28.1*	27.7-28.56	172.5	163.5-181.5
Pelvic flexure	Unbarbed (mean)	743.1	713.2-755.2	46.6	42.7-44.63	183.3	172.8-193.8
	Barbed (mean)	699.3*	671.6-727.1	32.0*	31.3-32.69	188.9	177.8-200.0

*indicates a statistically significant difference ($P < 0.05$) with values of the unbarbed group.

Construction time

In all intestinal tracts, enterotomy closure with barbed suture (caecum 610.4 sec, 95% CI 575.7-643.5 sec; pelvic flexure 699.3 sec, 95% CI 671.6-727.1 sec) was significantly faster (caecum $P = 0.034$; pelvic flexure $P = 0.039$) than with unbarbed suture (caecum 661.0 sec, 95% CI 629.0-693.0 sec; pelvic flexure 743.1 sec, 95% CI 713.2-755.2 sec).

Length of suture material used

The length of the suture material that was used was significantly shorter (caecum $P < 0.0001$; pelvic flexure $P < 0.0001$) in the barbed group (caecum 28.1 cm, 95% CI 27.7-28.56 cm; pelvic flexure 32.0 cm, 95% CI 31.3-32.69 cm) in all intestinal tracts, compared to the unbarbed group (caecum 41.6 cm, 95% CI 40.7-42.51 cm; pelvic flexure 46.6 cm, 95% CI 42.7-44.63 cm).

Bursting pressure

The difference in bursting pressure between the 2 groups was not significantly different (caecum $P = 0.294$; pelvic flexur, $P = 0.430$) for all intestinal tract specimens with barbed (caecum 172.5 mmHg, 95% CI 163.5-181.5 mmHg; pelvic flexure 188.9 mmHg, 95% CI 177.8-200.0 mmHg) or unbarbed sutures (caecum 178.3 mmHg, 95% CI, 167.4-189.3 mmHg; pelvic flexure 183.3 mmHg, 95% CI 172.8-193.8 mmHg).

Mode of failure

All constructs failed by tearing tissue on one side of the enterotomy. In most instances, the seromuscular layer started tearing at pressures below bursting pressure without causing leakage. When the submucosal and mucosal layer tore, complete bursting occurred.

Cost

The cost of each caecum and pelvic flexure closure was 15.1 euros for the unbarbed group and 84.12 euros for the barbed group.

Discussion

The results of our study showed that there were significant differences between barbed and unbarbed suture materials in terms of construction time and length of suture material used. Bursting pressure and mode of failure were not affected by suture material. The macroscopic appearances were similar, with a smooth inverting surface, but when unbarbed sutures were used, some exposed suture material was evident, particularly where the last knot of the second layer was tied. This observation is consistent with what has previously been reported (Gandini *et al.* 2013). Despite the care taken to bury all knots, it was impossible to completely avoid this occurrence. In our opinion, this could be a result of any of the following: the large volume of knots, the surgical technique, or the *ex vivo* setting, where tissue compliance could be impaired, thus making it more difficult to completely bury the knots.

Barbed sutures have several advantages compared to conventional sutures. As has been previously reported, barbed suture holds the edges in place, and does not slide backward between 2 bites (Nemecek *et al.* 2013). This allows suturing without the help of an assistant to keep tension on the suture thread. We found this property particularly useful in large intestine enterotomies. In our study, closure with barbed suture significantly reduced the length of suture material required, and significantly reduced surgical time. The actual time difference was minimal thus it is not likely to have an effect in a clinical setting. Clinically, the use of barbed sutures could potentially improve healing by leaving a smaller amount of suture material in the tissue (Trimbor *et al.* 1989). As has been noted in a previous study (Nelson *et al.* 2014), we also found that the difference in construction time could partly be due to the difference in length of the suture material used (45 cm of the barbed suture vs 76 cm of the unbarbed suture) (Nelson *et al.* 2014). This could result in a different amount of suture that needs to be pulled through the tissue after each bite, with loss of time occurring when handling the long, unbarbed sutures.

Avoiding knot placement could prevent weakening of the construct, reduce surgical time, and reduce the amount of foreign material left in the patient. While surgical time and suture material are reduced by using barbed suture, our results do not support the finding that knots are the weakest point of a suture line (Mulon *et al.* 2010), at least when applied with glycomer 631 on equine intestines. In fact, none of the constructs with unbarbed suture failed at the knot in our study, because tearing of the tissue always occurred first.

While Nelson and Hassel (Nelson and Hassel 2014) found a significant difference in bursting strength between anastomoses performed with barbed or unbarbed suture material, we found that there was no difference in bursting pressure between enterotomy closures with barbed or unbarbed sutures. This could be because we used a double layer pattern in the caecum and colon, while they used a single layer inverting suture (Nelson *et al.* 2014). Another difference between the results reported in our study and Nelson's may be because of the different methods that were used to measure bursting pressure. In our study, we distended the specimens with air and considered air bubbles leaking from the enterotomy to determine the maximal pressure sustained by the construct (Gandini 2006, Gandini *et al.* 2013) while Nelson and Hassel used stained fluid, which could have different behaviour (Nelson *et al.* 2014). As has been previously reported, we noticed that the barbed suture was easier to handle, although there was some dragging through the tissues (Nemecek *et al.* 2013). This may cause damage by creating larger suture tracts when the suture is pulled through tissue, but we were unable to objectively evaluate this issue in our study (Nelson *et al.* 2014). Another study showed that the use of barbed suture during intestinal closure in pigs did not cause more damage or inflammation than unbarbed suture (Demyttenaere *et al.* 2009).

Barbed suture proved effective for enterotomy closure and gastrointestinal anastomoses in pigs and humans, but there are drawbacks to its application because suture patterns with exposed barbs could cause intestinal damage or obstruction (Demyttenaere *et al.* 2009, Giusto *et al.* 2019, Buchs *et al.* 2012, Burchett *et al.* 2013). To more closely mimic the clinical setting, we chose to use the Cushing pattern as either a single layer or as the second layer in a 2-layer closure. This pattern also prevents problems related to exposed suture barbs, whereas a Lembert pattern would achieve the same results in terms of exposed suture barbs, but with more tissue inversion both in 1-layer or 2-layer closures. To perform the second layer in closures we preferred to use a new strand of suture, both in barbed and unbarbed groups. The procedure described here would increase costs in the clinical setting, but avoids using a contaminated strand for the second layer. The cost-per-enterotomy is then 5.5-fold higher for barbed sutures, and this could influence the surgeon's choice.

Evaluating the use of barbed suture material on cadavers could be regarded as a limitation of our study. Injured tissue handled during exploratory laparotomy may respond differently to the passage of suture material than healthy tissue, and may exhibit differences in bursting pressure. Furthermore, it has been hypothesised that intestinal motility could affect the behaviour of barbed suture lines (Giusto *et al.* 2019). Intestinal circular contractions, especially in pathological conditions, could cause a progression of the intestinal wall onto the barbs of the suture material, thus causing stenosis. However, one study shows that intestinal motility did not affect the use of barbed suture material in healthy pigs (Giusto *et al.* 2019).

Our results suggest that barbed suture is a viable alternative to unbarbed suture for enterotomy closure in horses. Another possible application of our results would be in laparoscopic intestinal biopsies (Schambourg *et al.* 2006, Bracamonte *et al.* 2008), where barbed sutures could allow effective intracorporeal suturing of the enterotomy without knot tying. However, further *in vivo* testing is necessary before applying the use of barbed suture material in patients.

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