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Title

Comparison of two end-to-end continuous sutures for intestinal anastomoses in dogs.

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Abstract

Background: Single-layer appositional closures are preferred to inverting or everting patterns, as submucosal apposition has been shown to promote primary healing of the intestinal wall, whereas inverted or everted closures require second-intention healing and can increase the risk of luminal stenosis or anastomosis site leakage. There are different suture patterns available, but relatively few studies comparing these aspects have been published.

The aim of this study was to compare two suture techniques for end-to-end anastomosis of the canine intestine (jejunum and colon): handsewn intestinal anastomosis by appositional simple continuous suture and inverting Cushing suture. The objectives of this study were to investigate 1.) whether the type of suture influences the specific effort to which the anastomosis site is submitted to, 2.) whether the anastomosis technique influences the diameter of the intestinal lumen and 3.) survival and complication rates in canine clinical cases undergoing end-to-end anastomoses.

Results: The equilibrium angle for implanting the sutures in an anastomosis is 35°, aspect completely fulfilled by the simple continuous suture. The efforts to which sutures are submitted to in anastomoses are minimal for the Cushing suture. The difference in size of the anastomoses' lumen between simple continuous suture and the Cushing suture are minimal, without being statistically relevant. The differences between the lumen of the anastomoses performed using PDS and those performed using PGA are not statistically relevant.

The retrospective analysis of the outcome for 676 dogs (clinical cases) that underwent intestinal resection and anastomosis reveals that the dehiscence rate was 1.48%, out of which 1.18% following simple continuous anastomoses, and 0.3% following Cushing anastomoses. Narrowing of the intestinal lumen due to anastomotic healing was not registered.

Conclusions: Use of the Cushing suture should be considered for performing an end-to-end intestinal anastomosis, although more studies are required to determine if there are any clinically significant differences between the sutures investigated in this study.

Keywords: Dog, End-to-end anastomosis, Colon, Jejunum, Cushing suture, Simple continuous suture.

Background

Intestinal resection and anastomosis is commonly performed in veterinary patients for treatment of intestinal foreign bodies, intestinal perforation, devitalized tissue secondary to vascular compromise, intestinal neoplasia, or intussusception and in patients that require revision of prior intestinal surgery [1, 2]. The potential major complications of intestinal anastomosis are leakage at the anastomosis site and luminal stenosis [1, 3, 4, 5, 6, 7, 8, 9, 10]. The anastomosis technique used may influence the diameter of the intestinal lumen, as well as the intraluminal pressure and the ability to withstand the normal peristalsis, with leakage or stenosis at the anastomosis site being the main postoperative complications.

A variety of surgical techniques for intestinal anastomosis has been described and analysed [11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21].

In veterinary medicine, a single-layer **appositional handsewn anastomosis** is preferred. Single-layer appositional closures are preferred to inverting or everting patterns, as submucosal apposition has been shown to promote primary healing of the intestinal wall, whereas inverted or everted closures require second-intention healing and can increase the risk of luminal stenosis or anastomosis site leakage, respectively [2, 3, 4, 5, 6, 7, 9, 10, 22, 23, 24, 25].

Outcomes following the use of interrupted and continuous suture patterns have been evaluated, and the incidence of leakage is comparable between these methods [13]. Other studies [3, 23, 26] show that

inverted sutures (Halstead interrupted sutures and Cushing suture) cause much less dehiscence compared to appositional or everting suture techniques.

Although bursting pressure and tensile strength have long been measured to evaluate anastomotic techniques [9, 14, 26, 27, 28, 29, 30, 31], no correlation was found between the bursting pressure and the tensile strength in the critical postoperative period [32, 33].

True approximation (appositional) with intestinal closure, however, is infrequent; eversion is seen histologically in 66% of simple interrupted closures. Eversion, inversion, or misalignment of tissue are seen in 38% of simple continuous closures [10, 14, 24, 34]. A study of the lumen narrowing by the inverted anastomotic flange showed, by gross estimate, an average of 54% for the Standard, 39% for the Halsted, 4% for the Gambee and 3% for the Navy suture [3].

The use of surgical **stapling devices** for intestinal anastomosis have also been described. There are several variants of realization: ***everting*** – end-to-end anastomosis using a triangulation technique and linear stapler ***(****TA -thoracoabdominal****)*** [35]; ***inverting-everting*** - functional end-to-end stapled anastomosis – FEESA [1, 18, 36, 37, 38, 39, 40, 41]; ***inverting*** - circular EEA Staplers [17, 42] and ***skin staples approximating*** anastomoses [14, 43, 44, 45, 46]. The intestinal staplers do induce inversion or eversion [2, 15, 47].

In a functional end-to-end anastomosis, inversion is created when using a linear cutting stapler (GIA stapler) and eversion when using a TA. This is the preferred technique for small intestinal anastomosis because the resulting stoma is larger than the original, and disparity in luminal size is easily accommodated [1, 18, 36, 37, 38, 39, 40, 41].

Inverting End-to-End Stapled Anastomoses produced significant luminal stenosis [17]. Evaluation of end-to-end skin stapled anastomosis dehiscence rates were similar to previously reported outcomes following resection and anastomosis in dogs [48].

The paucity of prospective veterinary literature regarding appropriate staple size and contraindications for use may, in part, play a role in the development of postoperative complications [2].

When comparing skin stapler end-to-end jejunal anastomosis to simple interrupted handsewn anastomosis, no differences in bursting strength, healing, or compromise of luminal diameter were appreciated, despite being an inverting-everting anastomosis [14].

In human medicine the evidence found was insufficient to demonstrate any superiority of stapled over handsewn techniques in colorectal anastomosis surgery [49, 50].

The aim of this study was to investigate comparatively two suture techniques for end-to-end anastomosis of the canine intestine (handsewn intestinal anastomosis by appositional simple continuous patterns and inverting Cushing closure).

The objectives of this study were to investigate 1.) whether the type of suture influences the specific effort to which the anastomosis site is submitted to, 2.) whether the anastomosis technique influences the diameter of the intestinal lumen and 3.) survival and complication rates in canine clinical cases undergoing end-to-end anastomoses.

We began from the hypothesis that end-to-end handsewn intestinal anastomosis by appositional simple continuous patterns and inverting Cushing closure offer different results regarding strength and maintaining a normal intestinal lumen. We also hypothesized that postoperative complications would be correlated with the type of suture used to perform end-to end anastomoses.

Results

The load with interior pressure (p) of an intestinal loop (flexible tube) leads to both circumferential (T1) and longitudinal (T2) efforts, calculated using the formulas: $T1 = \frac{\mathrm{pD}}{2} \quad T2 = \frac{\mathrm{pD}}{4}$, where D is the tube’s diameter.

The mathematic relation: $\frac{T1}{T2} = \frac{1}{2}$= tg2β, ties the efforts' intensities (circumferential and longitudinal) to which the intestine is submitted to.

Given these conditions, the value of the angle formed by the placement of the sutures with the circumferential direction (longitudinal axis of the intestine – y) called **implantation angle** (elevation) - β is 35°20'.

Thus, the internal pressure can be supported by the sutures only if they form a 35°20' implantation angle with the circumferential direction.

The vectorial scheme (Fig. 1) of the sutures' passing, considering the three techniques evaluated, reveals an implantation angle of approximately 35° for the simple continuous suture, 45° for the Cushing suture, and 0-10° for simple interrupted sutures respectively.

From the vectorial calculation of the effective specific effort (Tef) of the anastomoses ends, for the Cushing suture results the following relationship: $\bar{R}=\dot{F}1+\dot{F}2$, which, according to Pythagoras' Theorem results in R^2=$F1^2$+$F2^2$+2F1F2cos α

α=90° and cos α=0°, thus: R= $\sqrt{F1^2 + F2^2}$

For the simple continuous suture: $\bar{R}=\dot{F}1+\dot{F}2$

R'^2= $F1'^2$+$F2'^2$+2F'1F'2 cos α

0°<α<90° and cos α >0°

By comparing the vectorial relationships for the two sutures, it can be observed that to the sum: $F1'^2$+$F2'^2$, a value depending on α is added. In these conditions, R< R'. The orientation direction is different for the two results, R' being closer to the Y axis, which is why the section (A') to which it is applied, is smaller than section A, A>A'. The effective specific effort calculated for the two situations is:

Tef1 $= \frac{R}{A}$ $Tef2 = \frac{R'}{A'}$, resulting that Tef1<Tef2'.

The effort to which sutures are placed in an anastomose (N) was determined using the relation: $N=\frac{3}{4}pD\frac{t}{n}$, where “p” is the interior pressure, ”D” is the intestinal diameter, “t” is the distance between vectorial forces’ results, “n” is the number of suture layers.

By comparing the calculation elements of the studied suture, it results that given the same distance between sutures, „t” has different values, the relationship being T1<T2<T3, where T1 – Cushing suture, T2 – simple continuous suture, T3 – simple interrupted suture. In these conditions, the efforts to which sutures are submitted to in anastomoses (N) are minimal for the Cushing suture.

The data obtained by measuring **the anastomoses ends’ diameters** reveals that the single-layer simple continuous suture reduces the least the jejunum lumen diameter (12.55±4.55%) and colon diameter (9.32±2.27%) (Fig. 2)**.**

The inverting Cushing sutures maintains the jejunal lumen in the 78.6 – 88.9% range and the lumen of the colon in the 83.5-89.9% range (Fig. 3). The differences between the diameter of the simple continuous suture anastomoses’ lumen and the Cushing ones are minimal (Fig. 4 and Fig. 5), without being statistically relevant (p = 0.630 for the jejunum and p=0.632 for the colon after t-test, and p=0.322 for the jejunum and p=0.404 for the colon after applying the Independent samples Kruskal-Walis Test).

The differences between the lumen of the anastomoses performed using PDS and those performed using PGA, analysed applying the t-test, are not statistically relevant for anastomoses in simple continuous suture (p=0.966 for jejunum and p=0.686 for colon) and Cushing suture (p=0.698 for the jejunum and p=0.705 for the colon).

A retrospective analysis of 676 intestinal resections and end-to-end anastomoses performed in the Faculty of Veterinary Medicine between 1990 and 2020, reveal that 262 were conducted using simple continuous sutures and 414 using Cushing sutures.

Specific mortality: number of deaths due to anastomotic complications was 3/14.

Overall anastomotic dehiscence: total number of anastomotic dehiscence (evidenced by clinical and/or radiological findings) was 10 (3 jejunum and 7 colons; 8 following simple continuous sutures and 2 following Cushing suture). In our study, the dehiscence rates for canine anastomoses were 1.48%, out of which 1.18% were following simple continuous anastomoses, and 0.3% following Cushing anastomoses.

Stricture (narrowing in the bowel lumen due to anastomotic healing - evidenced by clinical and/or radiological findings) was not registered.

Reoperation: surgical re-intervention rate for anastomotic complication was 10/14.

The 14 anastomotic complications consisted in 10 dehiscences, out of which 4 had generalized peritonitis, and 4 had adherential complications at the anastomosis site between 14 and 28 days, (4 jejunum – all following simple continuous sutures).

Discussion

Our hypothesis that the two types of sutures offer different results in terms of strength and anastomosis diameter has not been confirmed, there was no significant difference ($p>0.05$).

The inclusion of the mathematical model for calculating the strengths of the anastomoses, instead of biomechanical testing of bursting pressure, was determined by the observations according to which no correlation was found between bursting pressure and tensile strength in the critical postoperative period [32, 33].

According to the elasto-plastic deformations theory of rubber tubes [51], when the elevation (implantation) angle of the wires in a flexible tube (intestine) differs from the equilibrium value ($\beta = 35°20'$), the tube will deform under the influence of the internal pressure up until the implantation angle is close to the equilibrium value.

Our hypothesis is that this phenomenon also occurs in intestinal anastomoses, which suggests that loops sutured using simple interrupted sutures or those performed using skin staples, will undergo the highest deformity when compared to those performed using continuous sutures.

The practical significance of rearranging the sutures towards the equilibrium value of the implantation angle consists in a higher risk of internal trauma to sutured ends, with consequences upon the watertightness of the sutures, the healing time and maintaining the lumen of the anastomosis site.

Direct comparison between the simple interrupted and continuous sutures in foreign body obstructions in dogs revealed no significant difference in postoperative dehiscence rate, in spite of reduced handling of the tissues, mucosal eversion, formation of adherences and that of a better apposition accomplished using a simple continuous technique [13, 34].

Anastomoses performed using intestinal staplers do induce inversion or eversion, with stapple implanting being performed at a β=45° angle, similar to that of the Cushing suture. Recently, re-evaluation of this technique beyond initial reports has demonstrated reduced dehiscence rates for canine anastomoses (4.8%) [44] and enterotomies (1.2%) [48], when compared to handsewn and auto-stapled techniques.

Coolman [14], who compared simple interrupted handsewn anastomosis with intestinal anastomoses with skin staples (implantation angle of 0-10° for both techniques) concluded that there is no difference in bursting strength, healing, or compromise of luminal diameter. However, there are studies which prove that the staple and crushing anastomosis techniques caused significantly less reduction in luminal radius than the inverting anastomosis technique [52].

Our data show that the inverting Cushing suture withstands higher luminal pressures.

According to the elasto-plastic deformations theory, suture implantation at an angle smaller than β = 35°20’, the intestine stretches and shrinks in diameter, and if the suture implantation is performed at an angle greater than the equilibrium value (Cushing suture - β=45°), under the action of pressure, the intestine will shorten and become wider. This phenomenon has also been suggested to be similar to the physiological response to increased intraluminal pressures [53]. These aspects could explain statistically non-significant differences obtained in our study when comparing the diameters of simple continuous sutured anastomoses and Cushing sutured anastomoses, even though Bellenger [22] states that inverting suture patterns result in greater narrowing of the intestinal lumen in dogs and cats.

The data we obtained by measuring the diameters of the anastomoses ends reveal that single-layer simple continuous suture causes the least reduction in intestinal lumen diameter, which confirms the statements of Harder and Vogelbach [54], who, in a study on 100 cases, encounter a stenosis rate of <1%.

The greater elasticity of simple continuous anastomoses calibre was explained by Max et al. [55] using the „coiled spring” effect. The potentially stenosing effect of inverting sutures is stated in the speciality literature as high, compared to approximating (appositional) sutures. The minimum differences recorded in this study can be explained by the double spiral spring arrangement of the Cushing suture (Fig. 6). This arrangement gives the anastomosis a compensatory increased elasticity to the reduction calibre caused by the inversion. The main shortcoming of the single-layer Cushing suture is the greater amount of suture material incorporated in the anastomosis, which may lead to a stenosing scaring ring.

Similar results regarding anastomoses sutured using polydioxanone (PDS) and polyglycolic acid (PGA) were also obtained by Kirpensteijn et al. [56], who showed no significant differences between the two suture materials, observed for most of the macroscopic or histological variable. Polyglactin 910 and polyglycolic acid are braided and retain good tensile strength for up to 28 days. Vicryl is commonly used for intestinal anastomosis in humans with good published success and is popular in Europe for veterinary use. In North America, monofilament sutures such as PDS and polyglyconate (Maxon) are more commonly used [10].

The clinical assessment shows a long-term survival rate of 97% after single-layer end-to-end anastomoses.

The most frequent postoperative complications of digestive anastomoses (small intestine and colon) in dogs are fistulas-dehiscence and stenosis [57, 58]. Other studies [3, 23, 26] reveal that inverting sutures (Halsted and Cushing) lead to fewer dehiscences, compared to everting or approximating sutures. Compared to anastomotic dehiscence rates reported to be as high as 28% [14, 18, 25, 59, 60, 61, 62, 63, 64, 65], the dehiscence rate in the present study was 1.48%. The mathematical analysis for the calculation of anastomosis’ strength carried out in this study offered the possibility to explain why the Cushing suture performed better under intraenteric postoperative pressures than the appositional continuous suture.

Adhesions were more common after single-layer appositional and everting suture patterns for end-to-end anastomosis in dogs and horses [4, 24, 66], although in the specialty literature it is shown that only everting patterns are more likely to elicit adhesion formation [4, 5, 67, 68]. A single-layer simple interrupted approximating suture may hold the potential stenosing risk, following adhesion formation between foreign bodies and sutures [69]. Our choice of an inverting or simple appositional continuous suture pattern and of small and less reactive suture materials may prevent this complication.

In dogs, single-layer opposing suture patterns have the advantages of excellent apposition of intestinal layers, maintenance of adequate luminal diameter, fast and simple execution and biomechanical resistance sufficient to withstand the physiological pressures produced in the bowel of this species [14, 33, 34, 39]. The results we obtained with the Cushing suture have been associated with fewer short-term issues than continuous appositional suture and have been suggested to be superior to other single-layer appositional techniques, in which the mucosa tends to evert.

Some limitations of our study are the use of cadaver material and the fact that all surgeries were performed by a single surgeon with more than 15 years of experience. Whilst this was done to minimize random error, the findings in this study might be affected by the surgeon's individual technique and experience. Enrolling multiple surgeons may reduce the bias of surgeon preference in future studies.

Conclusions

The equilibrium angle for implanting the sutures in an anastomosis is 35°, aspect completely fulfilled by simple continuous suture. Comparative determinations of the effort to which the anastomoses ends and sutures respectively, are submitted to, reveal the superiority of the Cushing suture, compared to simple continuous suture. Both suture techniques influence the intestinal diameter without any significant statistical differences when compared to one another. Retrospective analysis of the clinical cases reveals that the type of sutures used influences neither success of the suture, nor the number of dehiscences. Therefore, use of the Cushing suture or a simple appositional continuous pattern should be considered for performing an end-to-end anastomosis, although more clinical studies are required to determine if these differences are clinically significant.

Methods

This option was chosen because in existing bursting pressure studies there is no explanation as to why some single-layer sutures withstand higher pressures than others do, or even why single-layer sutures withstand higher pressures than the double-layer sutures.

In order to calculate the **strengths of the anastomoses**, we used as a mathematic model, formulas used to determine constructive parameters for flexible tubes made out of rubberized cloth [51], a choice based on existent analogy with the intestinal layers (serosa, muscularis, submucosa and mucosa) and the carcase of a rubberized cloth tube (glossy rubber coating, elastic rubber, rubber-impregnated textile yarn cord, slip rubber coating). In both situations, the resistance layers – submucosa, and the yarn cord – occupy the same position and are submitted to the same types of effort. The yarn cord was similar to the sutures placed in an anastomosis.

Mathematic corelations were conducted for end-to-end handsewn anastomosis (appositional simple continuous patterns, simple interrupted) and Cushing continuous closure.

We determined the *equilibrium angle* of suture placement, the effective specific effort to which the anastomosis ends were submitted to and the *exerted effort* upon the sutures placed in an anastomosis.

The canine cadavers originated from patients that either succumbed due to untreatable medical conditions, or were euthanized due to medical conditions, unrelated to the gastrointestinal tract. The time between death or euthanasia of animals and intestinal anastomosis realization ranged from 4 - 48 hours.

All intestinal (jejunal and colonic) segments were collected from 26 dogs (13 females, 13 males, all mixed breed), with weights ranging from 12 to 35 kg (22.5 kg ± 4.9 kg) and reported ages ranged from 1 - 7 years (3.4 years ±1.7 years), the number of anastomoses per session ranging from 1 to 12 (median 6.5 anastomoses).

Within 1-2 hours of euthanasia or death, the gastrointestinal tract was examined to confirm there were no gross abnormalities present. Animals with intestinal diseases were excluded from the study.

The jejunum and colon were then harvested. Ingesta was milked towards the transected stumps. Jejunal and colon segments were stored at 4 °C until utilized. Each specimen had a length of 40-60 mm. The jejunal and colonic segments from each cadaver were randomly allocated and equally distributed amongst the 2 groups (Table 1). A total of 216 anastomoses were performed.

Table 1 Lumen diameter of jejunum and colon segments and numerical distribution by groups

End-to-end intestinal anastomosis	**Normal lumen diameter (mm)**			**Groups of single-layer suture techniques**	**Number of anastomoses (n)**	**Suture materials Groups**	
	Mean	**St Dev**	**CI 95%**			**PGA (n)**	**PDS (n)**
Jejuno-jejunal	11.11	±1.809	10.61-11.60	Simple, continuous appositional suture	54	27	27
				Inverting Cushing suture	54	27	27
Colo-colonic	13.33	±1.763	12.85-13.81	Simple, continuous appositional suture	54	27	27
				Inverting Cushing suture	54	27	27

Legend: n Sample size, Mean, St Dev Standard Deviation, CI confidence interval, PGA Polyglycolic acid, PDS Polydioxanone

Anastomosis construction

We conducted end-to-end anastomoses (jejunal and colonic) on canine cadavers, using two techniques (simple appositional suture, and inverting Cushing suture respectively). We conducted 108 jejunal anastomoses and 108 colonic anastomoses, out of which 54 consisted in simple approximating suture and 54 consisted in inverting Cushing suture on each intestinal segment. All 216 were performed by the same surgeon. The intestinal stumps were fixed using two Doyen intestinal clamps. Intestinal segments were sharply transected using Metzenbaum scissors. Stay sutures were placed at the mesenteric and antimesenteric borders of each portion of transected jejunal or colonic segment to allow the assistant to apply tension to appose the intestinal portions as required during the anastomosis. The anastomosis began on the mesenteric border by applying an “U” suture to enclose the portion between the mesenteric sheaths. Suture bites were taken approximately 2–3 mm from the incised edge.

For each group, we used 1.5 m (4-0) with Atraloc, 22 mm needle, Poliglicolic acid - Vicryl - Poliglactin 910 -Ethicon USA) (27+27) and 1.5 m (4-0) with Atraloc, 22 mm needle, Polydioxanone – PDO- Biosintex Romania (27+27).

Determining the diameter of the anastomoses (mm)

Determination of the diameter of the anastomoses (mm) was accomplished using callipers and by direct measuring of the intestinal lumen immediately after each anastomosis was completed. For interpretation purposes, the average diameter of the anastomoses was referred to as a percentage of the normal intestinal diameter for each suturing technique.

Medical records from the Faculty of Veterinary Medicine, Timisoara, Romania were retrospectively evaluated to identify all dogs that underwent intestinal resection and anastomosis between January 1, 1990, and December 31, 2020. Including criteria into the study where dogs with jejunum or colon resection and end-to-end anastomosis by simple continuous or Cushing sutures, performed for the treatment: of intestinal perforation, devitalized tissue secondary to vascular compromise, and intussusception. Dogs that underwent multiple concurrent anastomoses, those lost to follow-up (information not available either by review of the medical record or through telephone contact with the owner or referring veterinarian), and those that died or were euthanized in the postoperative period for reasons unrelated to anastomotic failure were also excluded. The anastomoses were performed by two experienced surgeons. The choice of suturing technique was based on the experience of both surgeons, with continuous appositional suturing being preferred for small dogs (<10 kg) and Cushing suture in dogs weighing more than 10 kg.

Types of outcome measures were: a) Specific mortality: number of deaths due to anastomotic complications; b) Overall anastomotic dehiscence: total number of anastomotic dehiscences (evidence by clinical and/or radiological findings); c) Stricture: narrowing of the intestinal lumen due to anastomotic healing (evidence by clinical and radiological exam); d) Reoperation: surgical re-intervention for anastomotic complications.

Statistics

Descriptive statistics for the cadavers, intestinal segments, number of anastomoses in each group, number of sutures placed and time between euthanasia and testing were calculated and reported as mean ± standard deviation (SD).

The data was statistically calculated using IBM SPSS Statistic Version 23 and Minitab Release 14.20.

For analysing the diameters of jejunal and colonic anastomoses, performed using two suturing techniques (simple appositional suture, and inverting Cushing suture respectively), we used two-sample T-test (parametric test), Kruskal-Walis Test (non-parametric test) and 95% confidence intervals. Values of $P < 0.05$ were considered significant.

We also used the parametric t-test for comparative analysis of the influence the suture material (PGA vs PDS) has over the two techniques used to perform the jejunum and colonic anastomoses (simple appositional suture, and inverting Cushing suture respectively). The significance level is $p=0.05$.

For our clinical casuistry, we compared the occurrence frequencies (dehiscence, adherences, second surgeries, mortality, success) in relation to the type of suturing technique used (simple appositional suture, and inverting Cushing suture respectively) and the intestinal segment (jejunum and colon). We used the independence and homogeneity hi^2 test, linked to the frequencies of presentation of such cases. The categories are comprehensive and mutually exclusive: any subject may belong to one category and one alone.

List of abbreviations

TA: thoracoabdominal

FEESA: functional end-to-end stapled anastomosis

EEA: end-to-end anastomosis

GIA: gastrointestinal anastomosis

PDS: polydioxanone

PGA: polyglycolic acid

PDO: polydioxanone

Figure legends

Fig. 1 Distribution of circumferential and longitudinal forces (efforts) to which the anastomosed intestine is subjected to.

Sub-figure **I** depicts efforts in case of Cushing Type suture. Sub-figure **II** depicts efforts in case of simple continuous suture.

Legend:

X and **Y** represent cartesian coordinates in which Y represents the longitudinal axis of the intestine; **D and D’** are the diameters of the intestine; **B and B’** represent the areas of the intestinal lumen; **A and A’** are the sections to which R applies; **R and R’** are the action resultants of the vector forces F1, F1’, F2 and F2’; β represents the suture implantation angle and α represents the angle formed by the vector forces F1 and F2.

Fig. 2 Percentage of lumen reduction - single-layer simple continuous suture.

Mean ± St dev

Fig. 3 Percentage of lumen reduction - Cushing continuous suture.

Mean ± St dev

Fig. 4 Ex-vivo, variation of jejunal lumen size after anastomosis.

Variation of jejunal lumen size under the influence of end-to-end anastomoses by single-layer simple continuous suture and single-layer inverting Cushing suture.

Fig. 5 Ex-vivo, variation of colon lumen size after anastomosis.

Variation of colonic lumen size under the influence of end-to-end anastomoses by single-layer simple continuous suture and single-layer inverting Cushing suture.

Fig. 6 Disposition of suture thread.

Sub-figure **a** depicts the simple continuous suture before and after the increase of intra-intestinal pressure.

Sub-figure **b** depicts the Cushing suture before and after the increase of intra-intestinal pressure.

Additional Files Legends

Additional file 1 of The lumen diameter simple continuous versus Cushing suture. Raw data collected in this study. The data included in this document represent the basis for the statistical analysis.

Additional file 2 of The statistic lumen diameter. Results of the statistical analysis are presented here.

Additional file 3 of The consent for medical or surgical procedures.

Additional file 4 of The cooperation agreement university - individual person (owner).

Additional file 5 of The clinical objective exam sheet - Surgery_ Hospithal_Discharge. Document templates from this file are those based on which we conducted the retrospective clinical study.

Declarations

- **Ethics approval and consent to participate**

  Approval for the use of cadavers for research was obtained from the University of Agricultural Sciences and Veterinary Medicine from Banat Administration Council and Animal Ethics Committee. The Bioethics Commission is an independent body, appointed within the USAMVBT based on the decision of the Board of Directors no. 4316 of 24.06.2016 and the decision of the University Senate no. 4425 of 29.06.2016 following the MENCS address no. 87857 of 13.06.2016, https://www.usab-tm.ro/utilizatori/calitate/file/regulamente/R084.pdf

- **Consent for publication**

  Informed consent was given by the owner of all dogs for all the procedures and treatments. This comprised a written consent form, read and signed by the owner when dogs were admitted to the Clinical Veterinary University hospital between 2016-2020 (**Additional file 3**), and a verbal consent between 1990-2016. The written consent is attached as additional information **(Additional files 4).**

- **Availability of data and materials**

  The datasets used and/or analysed during the current study are partially included in this published article [as supplementary information files]and all data are available from the corresponding author on reasonable request.

- **Competing interests**

  The authors declare that they have no competing interests.

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- **Authors' contributions**

CI participated in the planning of the study, supervised and coordinated the research, performed the surgeries, wrote and reviewed the paper.

DR, SB, ZC and SL performed ex vivo study, collected data, and participated in reviewing the paper.

IB performed mathematical analysis, data analysis and statistics.

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- **Authors' information (optional)**

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Figures

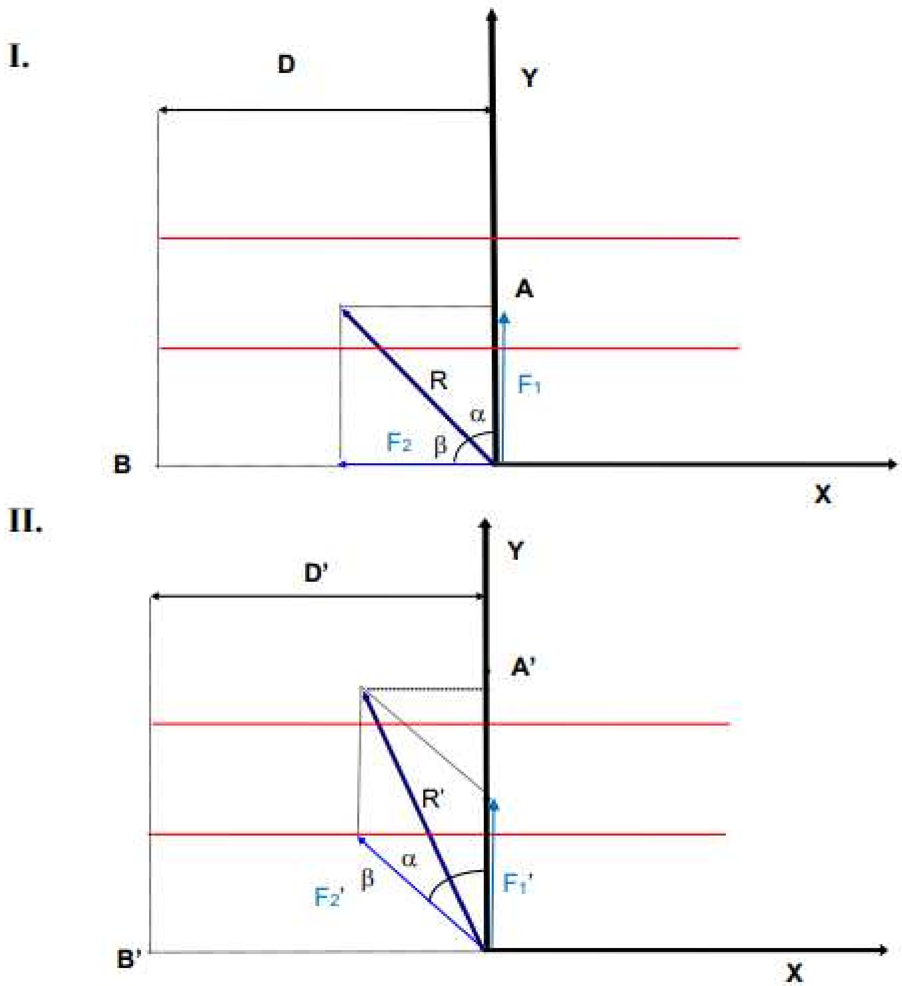

Figure 1

Distribution of circumferential and longitudinal forces (efforts) to which the anastomosed intestine is subjected to. Sub-figure I depicts efforts in case of Cushing Type suture. Sub-figure II depicts efforts in case of simple continuous suture. Legend: X and Y represent cartesian coordinates in which Y represents the longitudinal axis of the intestine; D and D' are the diameters of the intestine; B and B' represent the areas of the intestinal lumen; A and A' are the sections to which R applies; R and R' are the action resultants of the vector forces F1, F1', F2 and F2'; β represents the suture implantation angle and α represents the angle formed by the vector forces F1 and F2.

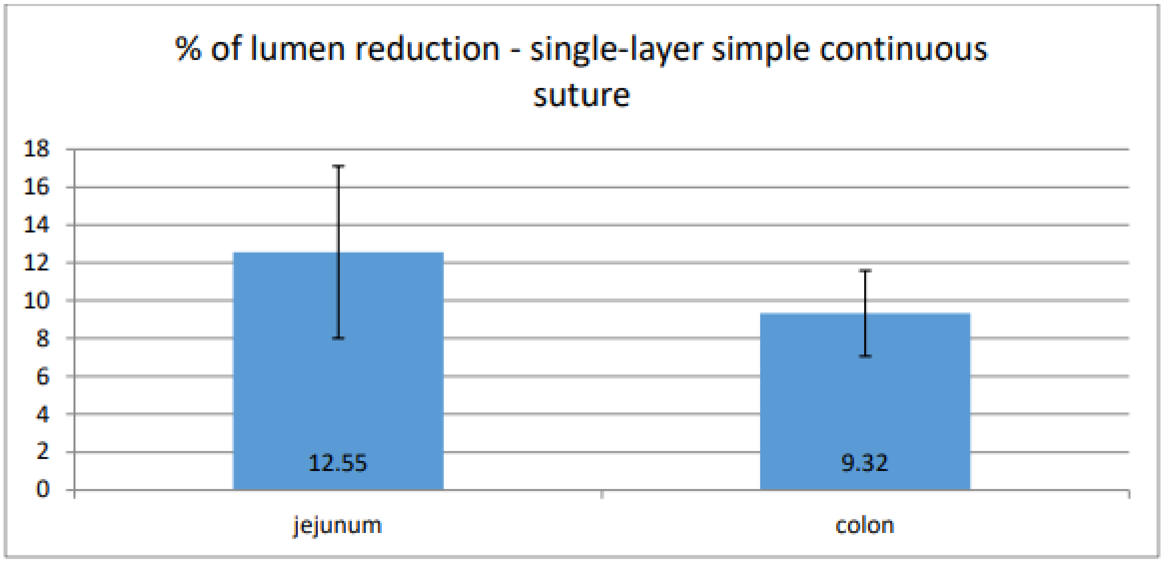

Figure 2

Percentage of lumen reduction - single-layer simple continuous suture. Mean ± St dev

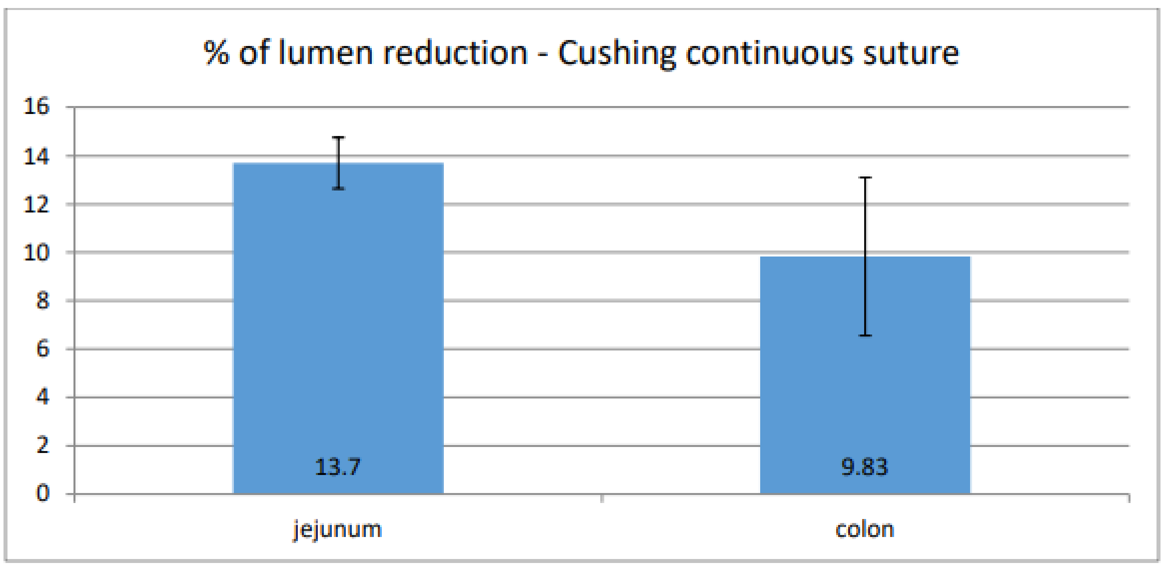

Figure 3

Percentage of lumen reduction - Cushing continuous suture. Mean ± St dev

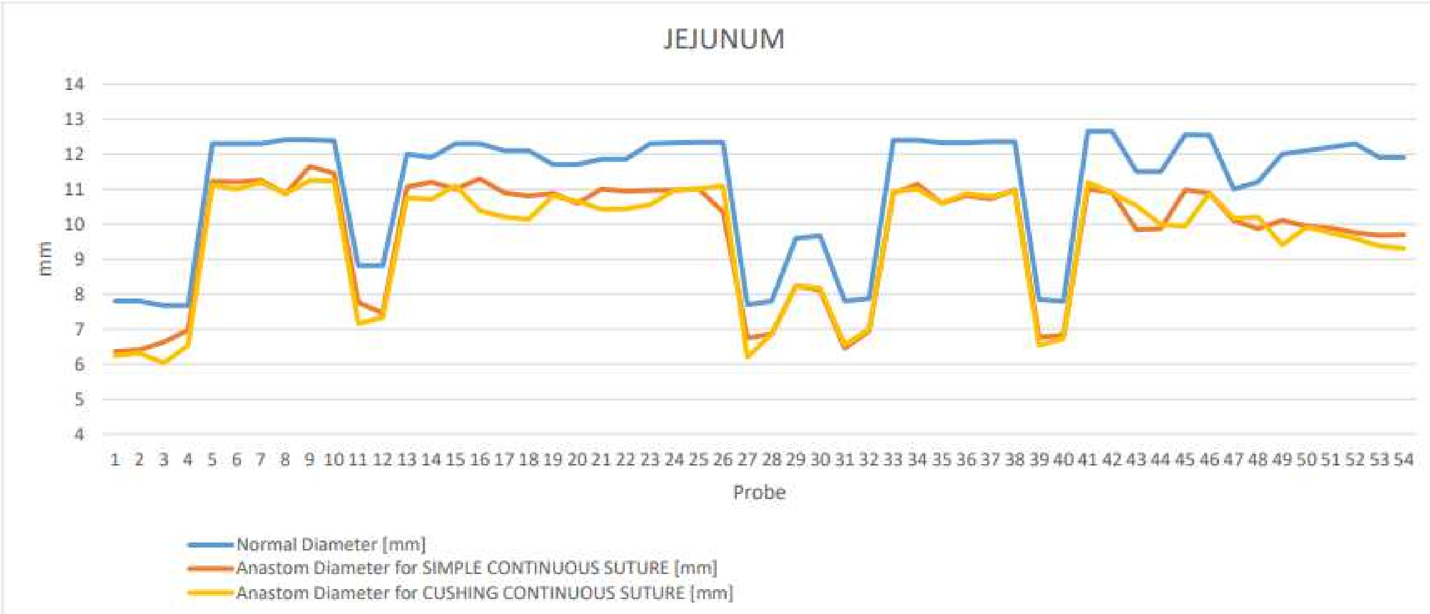

Figure 4

Ex-vivo, variation of jejunal lumen size after anastomosis. Variation of jejunal lumen size under the influence of end-to-end anastomoses by single-layer simple continuous suture and single-layer inverting Cushing suture.

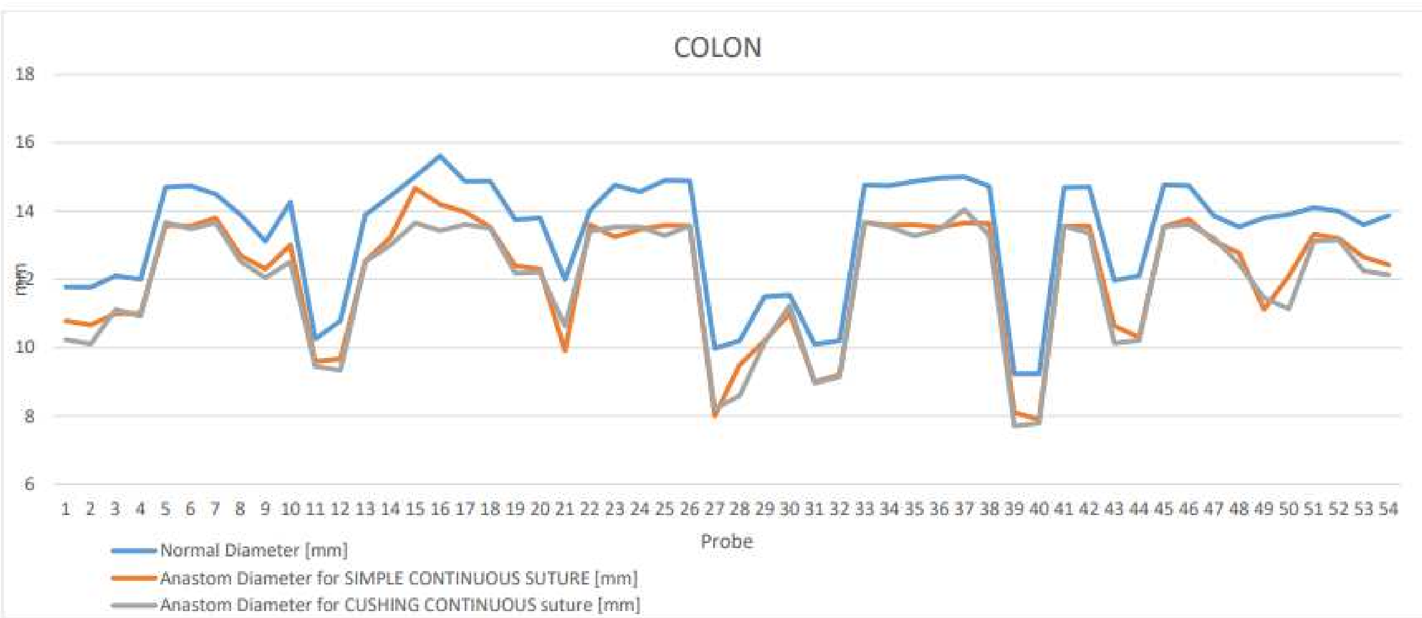

Figure 5

Ex-vivo, variation of colon lumen size after anastomosis. Variation of colonic lumen size under the influence of end-to-end anastomoses by single-layer simple continuous suture and single-layer inverting Cushing suture.

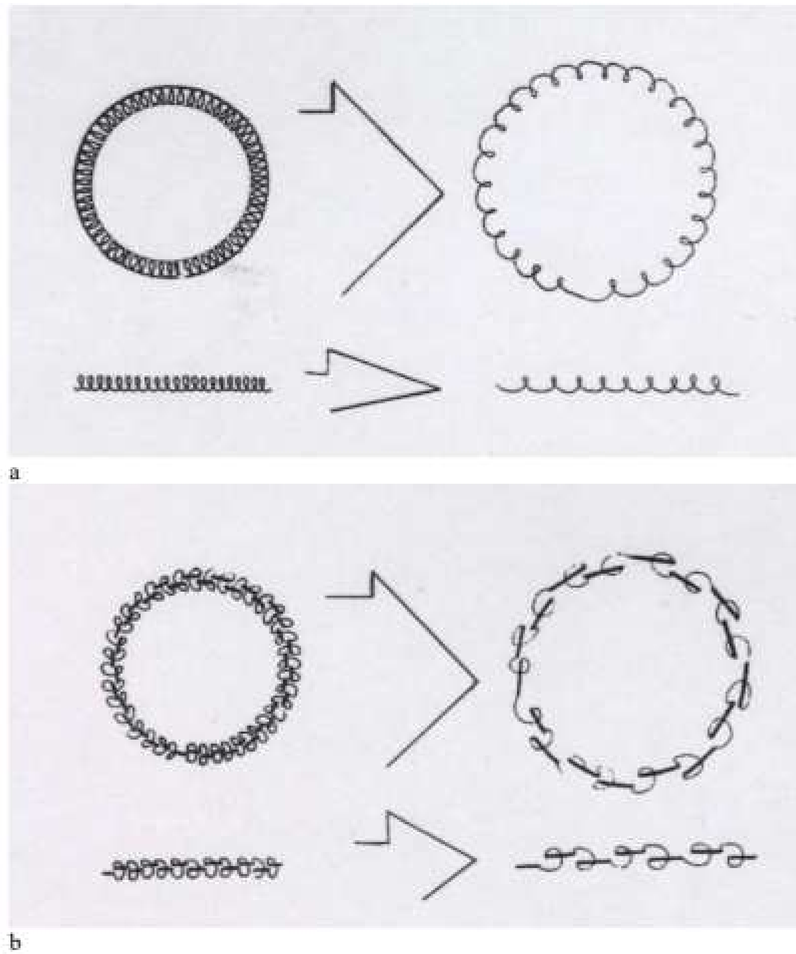

Figure 6

Disposition of suture thread. Sub-figure a depicts the simple continuous suture before and after the increase of intra-intestinal pressure. Sub-figure b depicts the Cushing suture before and after the increase of intra-intestinal pressure.

Supplementary Files

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