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ORIGINAL ARTICLE

Optimal sutures for use in the abdomen: an evaluation based on the formation of adhesions and abscesses

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Abstract
Purpose This study explored the optimal suture materials for use in the peritoneal cavity based on the formation of adhesions and abscesses under clean and contaminated conditions.
Methods The parietal peritoneum and muscle layer of rats were incised. The incision was followed by interrupted suturing in the clean group. A suspension of *E. coli* (1.0×10^6) plus *Bacteroides fragilis* (1.0×10^5) was sprayed onto the incision in the contaminated group, followed by interrupted suturing. Four types of sutures were used: nonabsorbable multifilament silk, absorbable multifilament Polyglactin 910 (Vicryl®), absorbable monofilament Polydioxanone (PDS®), and Poliglecaprone 25 (Monocryl®). The rats were killed at 2, 4 or 8 weeks after the surgery.
Results The incidence of adhesions in the clean group was low with Polyglactin 910. The incidence of adhesions was 96 % or higher regardless of the suture type in the contaminated group. The incidence of severe adhesions was low with Polyglactin 910 and Poliglecaprone 25 and significantly higher with Polydioxanone in the contaminated group. The incidence of abscess formation around the silk was significantly higher than the other three types of sutures in the contaminated group.
Conclusion Polyglactin 910 was less likely to form adhesions than the other three types of sutures under both conditions, suggesting that Polyglactin 910 may be the optimal type of suture to use in the peritoneal cavity.

Keywords Adhesion · Suture · Contamination · Infection · Gastrointestinal surgery

Introduction

Various materials, instruments and various types of sutures are employed for the ligation/suturing of tissues in the peritoneal cavity, anastomosis of the bowel, and closure of the abdominal wall in gastrointestinal surgery. Adhesions can be promoted by intraperitoneal infection, bleeding, local tissue ischemia/crushing during operative procedures such as ligation, mechanical injury of the surface of peritoneum by gauze, etc., and foreign bodies remaining in the peritoneal cavity (starch and other powders, suture, etc.) [1–4].

Small bowel obstruction (SBO) is one of the most troublesome complications that can develop even years after abdominal surgery, and adhesions are a major factor responsible for postoperative SBO [5]. A large number of studies have been conducted to determine the optimal protocols for reducing the incidence of adhesions, but no clinically feasible method has yet been established. Efforts have therefore been made to minimize mechanical injury to the peritoneum and to minimize residual blood, bacteria, etc. in the peritoneal cavity by adequate lavage [4].

Sutures can be divided into four types depending on two factors, i.e., on whether they are absorbable or nonabsorbable, and whether they are the monofilament or multifilament type. The prerequisite features of sutures for gastrointestinal surgery are that they should (1) have a high resistance to infection, (2) induce weak tissue reactions, (3)

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have sufficient tensile strength, (4) and be capable of rapid absorption after wound healing.

Absorbable monofilament sutures are thought to be excellent for preventing infection [6–8]. However, the prerequisites of the optimal suture are not simple, since optimal sutures are easy to knot and difficult to loosen after ligation.

The type and thickness of the sutures used for surgery are selected by each hospital or by each surgeon depending on the site, organ/tissue to be ligated, and the presence/absence of infection in the surrounding area.

This study experimentally analyzed the frequency and strength of the adhesions and abscess formation around the sutures under clean and contaminated conditions to determine the optimal type of suture for ligation and suturing within the peritoneal cavity.

Methods

Sutures

Four types of sutures were used for this experiment; non-absorbable multifilament silk, absorbable multifilament Polyglactin 910 (Vicryl®), absorbable monofilament Polydioxanone (PDS®), and absorbable monofilament Poliglecaprone 25 (Monocryl®). All of the sutures were needle-attached UPS 3-0. USP 3-0 thickness was selected because USP 3-0 sutures are usually used in the peritoneal cavity regardless of the suture types. Two types of absorbable monofilament sutures (Polydioxanone and Poliglecaprone 25) were selected because of the large difference in the duration of maintenance of the tensile strength (tensile strength maintained for about 6 weeks with Polydioxanone and for 3 weeks with Poliglecaprone 25) [9, 10].

Experimental animals

A total of 114 male Wistar rats, about 8 weeks old and weighing about 200–250 g (CLEA Japan, Inc. Tokyo, Japan), were used for this study. The rats were given food and water ad libitum.

Establishment of an intra-abdominal contaminated model

An intra-abdominal contaminated model was created by intraperitoneal administration of a suspension of *Bacteroides fragilis* (ATCC25285) and *Escherichia coli* (ATCC25922). *E. coli* was incubated with heart infusion medium, while *Bacteroides fragilis* was incubated with *Bacteroides* medium. Three suspensions composed of the two bacteria at varying mixture ratios were prepared to determine the optimal bacterial inoculation level—A: A mixture of *E. coli* 10^8 cfu/ml and *Bacteroides* 10^7 cfu/ml, B: a mixture of *E. coli* 10^7 cfu/ml and *Bacteroides* 10^6 cfu/ml, and C: a mixture of *E. coli* 10^6 cfu/ml and *Bacteroides* 10^5 cfu/ml [11–13].

Pentobarbital [Nembutal®; about 0.25 mL (0.1 mL/100 g)] was injected intraperitoneally. The abdomen was opened through a median incision, followed by spraying with 2 mL of a mixed bacterial suspension. The abdomen was closed with silk sutures. Two rats were assigned to each group. Both rats inoculated with suspension A died 1 day after the surgery. One of the two rats inoculated with suspension B died 1 day after the surgery. Both rats inoculated with suspension C survived for 7 days after the surgery. Therefore, suspension C was used for the main experiment.

Surgical procedure

The abdomen was opened by a median incision following intraperitoneal injection of pentobarbital. A 2-cm incision of the parietal peritoneum and muscle layer was made on either side. The clean wound group had the peritoneal defects sutured with one of the four sutures (silk, Polyglactin 910, Polydioxanone, Poliglecaprone 25) using five-stitch interrupted suturing (5 ligations) at intervals of 4 mm. The contaminated wound group had a 2-mL suspension composed of a mixture of *E. coli* (1.0×10^6) and *Bacteroides fragilis* (1.0×10^5) sprayed into the peritoneal cavity, followed by interrupted suturing of the defects with one of the four sutures in the same way as the clean wound group. Two ml of blood were taken from the inferior vena cava of each rat and sprayed into the peritoneal cavity of both groups to promote the formation of adhesions.

Twelve rats and 15 rats each were allocated to each of the four types of sutures in the clean and contaminated wound groups, respectively, because of the greater possibility of death of the animals in the contaminated group. Four and 5 rats from the clean and contaminated wound groups, respectively, were killed at 2, 4 and 8 weeks after the surgery.

Evaluation of adhesion and local infection

Adhesion formation was evaluated according to the Adhesion Severity Scoring System proposed by Oncel et al. [14] (Table 1). The incidence and strength of the adhesions were evaluated. The presence/absence of abscess around the suture was assessed macroscopically. The assessment was performed by one of the authors (SS) who was blinded to the assignment information.

Statistical analysis

The statistical analysis was conducted using the χ^2 test. Differences were considered to be statistically significant when $P \leq 0.05$.

This study was approved by the institutional review board (approval code: 074012) and the experiments were performed according to the guidelines for animal experimentation of Tokai University.

Results

A total of 108 rats were used for the assessment of adhesions. Six rats died 3 days after surgery. All six rats underwent necropsy without significant findings. Any rats that died prematurely were excluded from the evaluation.

Incidence of adhesions (Table 2; Fig. 1)

The incidence of adhesions during the first 4 weeks after surgery was 100 % and did not differ among the four types of sutures in the contaminated wound group. The incidence of adhesions in the clean wound group was lower with Polyglactin 910, thus differing significantly from that with Polydioxanone.

Table 1 Adhesion Severity Scoring System (Oncel et al. [14])

Level	Definition
0	No adhesion
1	Loose filmy adhesion that can be separated by blunt dissection
2	Adhesion requiring <50 % sharp dissection for separation
3	Adhesion requiring >50 % sharp dissection for separation
4	Serosal injury
5	Full-thickness injury

Incidence of severe adhesions (Table 3; Figs. 2, 3)

The incidence of severe adhesions (level 4 or higher according to the Adhesion Severity Scoring System proposed) was the highest (84.7 %) with Polydioxanone, differing significantly from that for the other three types of sutures in the contaminated wound group. The incidence of severe adhesions in the clean wound group was low (8.3 %) with Polyglactin 910 and significantly high (62.5 %) with Polydioxanone. Hard and straight protrusions of the two cut ends of the suture extending into the adhesions were observed in the wounds sutured with Polydioxanone (Fig. 3).

Abscess formation (Table 4; Fig. 4)

No abscess formation was observed, regardless of the type of suture used in the clean wound group. The incidence of abscess formation around the silk sutures in the contaminated wound group was significantly higher than that around the other three types of sutures. In addition, the

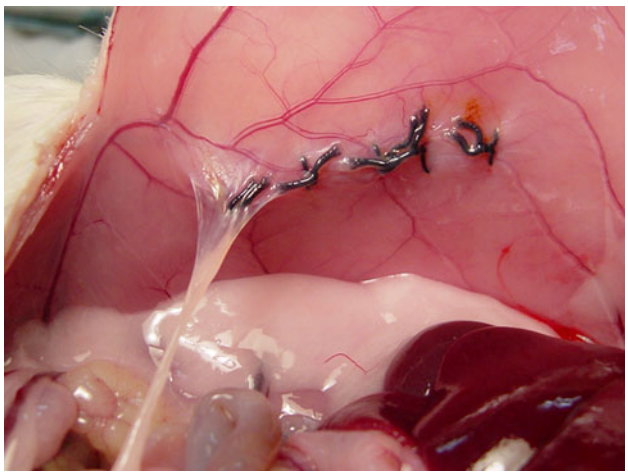

Fig. 1 Short adhesion arising around a silk suture at 4 weeks after the surgery in the clean group (adhesion severity score level 1)

Table 2 incidence of adhesions

	Clean condition					Contaminated condition			
	2wk	4wk	8wk	total (%)		2wk	4wk	8wk	total (%)
Silk	7/8	6/8	8/8	21/24 (87.5)		10/10	10/10	7/8	27/28 (96.4)
Polyglactin 910	5/8	4/8	6/8	15/24 (62.5)	※	10/10	8/8	9/10	27/28 (96.4)
Polydioxanone	8/8	7/8	7/8	22/24 (91.7)	※	8/8	8/8	10/10	26/26 (100.0)
Poliglecaprone 25	5/8	7/8	7/8	19/24 (79.2)		8/8	8/8	10/10	26/26 (100.0)

wk weeks

※ $p < 0.05$

Table 3 incidence of intensive level 4 or 5 adhesions

	Clean setting						Infected setting					
	2wk	4wk	8wk	total (%)			2wk	4wk	8wk	total (%)		
Silk	5/8	1/8	1/8	7/24 (29.2)		※	9/10	4/10	3/8	16/28 (57.1)		※
Polyglactin 910	1/8	0/8	1/8	2/24 (8.3)	★		10/10	1/8	0/10	11/28 (39.3)	★	
Polydioxanone	6/8	4/8	5/8	15/24 (62.5)			6/8	8/8	8/10	22/26 (84.7)		
Poliglecaprone 25	2/8	5/8	1/8	8/24 (33.3)			4/8	6/8	0/10	10/26 (38.5)	★	

※ $p < 0.05$ ★ $p < 0.001$

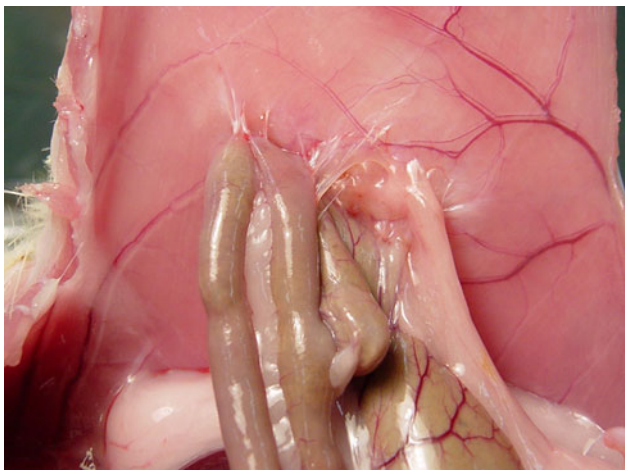

Fig. 2 Long adhesion arising around a Polydioxanone suture at 8 weeks after the surgery in the contaminated group (adhesion severity score level 4)

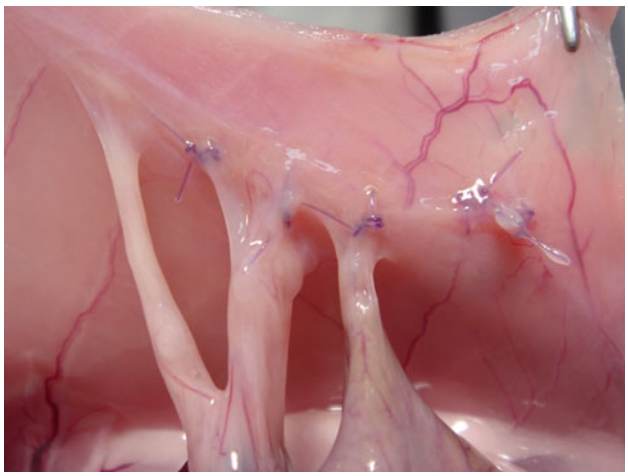

Fig. 3 Severe adhesion at 2 weeks after surgery in the clean group. Hard protrusions of the two cut ends of Polydioxanone are observed extending straight out of the adhesion

incidence of abscess formation in the contaminated wound group decreased over time.

Discussion

Intraperitoneal infection, bleeding and foreign bodies, such as suture materials, can promote the formation of adhesions [1–4]. Adhesions occur at a high rate following abdominal surgery; the reported incidence is 67 % in autopsy cases and 93 % in cases undergoing abdominal surgery [15, 16]. Beck et al. [17] reported that 14 % of patients that undergo bowel resection and anastomosis develop SBO within 2 years, and 2.6 % of these patients require adhesionlysis. The recurrence rate of SBO after adhesionlysis is 7 % at 1 year, 18 % at 10 years, and 29 % at 30 years [18]. These results suggest that adhesions are unlikely to disappear after they have formed.

Sutures can be divided into four types according to their absorptivity (absorbable or nonabsorbable) and filament structure (monofilament or multifilament). Elek et al. [6] experimentally demonstrated that even a small number of staphylococci can form a subcutaneous abscess when silk sutures are used. This suggests that nonabsorbable sutures, that remain as foreign bodies for a prolonged period of time, can promote wound infection or adhesions. Therefore, absorbable sutures with a sufficient tensile strength may be superior to nonabsorbable sutures. Geiger et al. [7] investigated bacterial transfer on the surfaces of absorbable monofilament and multifilament sutures. Bacterial transfer by the capillary phenomenon was only observed with multifilament sutures. Chu et al. [8] reported that the amount of bacteria adhering to the suture surface was smaller with absorbable monofilament sutures than absorbable multifilament sutures, indicating the possibility that the surface form of

Table 4 Incidence of abscess around the suture under the infected setting

	2wk	4wk	8wk	total (%)
Silk	9/10	7/10	7/8	23/28 (82.1)
Polyglactin 910	6/10	1/8	0/10	7/28 (25.0)
Polydioxanone	4/8	0/8	0/10	4/26 (15.4)
Poliglecaprone 25	4/8	1/8	0/10	5/26 (19.2)
Total	23/36	9/34	7/38	
(%)	(63.9)	(26.5)	(18.4)	

★ $p < 0.001$
※ $p < 0.05$

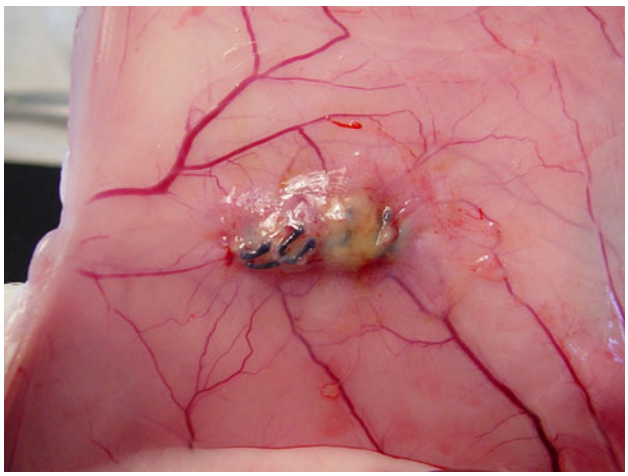

Fig. 4 Abscess arising around a silk suture at 2 weeks after the surgery in the contaminated group

the sutures may serve as an important factor in the onset of infection under contaminated conditions. Therefore, absorbable monofilament sutures may be excellent for preventing infection.

The duration of maintenance of the tensile strength differs considerably, even among absorbable sutures. The type and thickness of the sutures used in the peritoneal cavity are selected at each facility or by each surgeon depending on the site, organ/tissue to be ligated, and the presence/absence of infection.

This study sutured peritoneal defects with the following four types of sutures using needle-attached USP 3-0; silk (nonabsorbable multifilament suture), absorbable multifilament suture Polyglactin 910 (Vicryl®), slowly absorbable monofilament suture Polydioxanone (PDS®) and rapidly absorbable monofilament suture Poliglecaprone 25 (Monocryl®), because nonabsorbable monofilament sutures such as Nylon and Polypropylene (Prolene®) have not been used for ligation within the peritoneal cavity or for suturing of peritoneal defects. The incidence and strength of adhesions were evaluated in accordance with the criteria proposed by Oncel et al. [14] at 2, 4 and 8 weeks after the surgery.

The incidence of adhesions under clean conditions was lower for Polyglactin 910 than for Polydioxanone. The incidence of severe adhesions was higher for Polydioxanone than for Polyglactin 910 and silk. The incidence of adhesions did not differ among the four types of sutures under contaminated conditions; however, the incidence of severe adhesions was significantly higher for Polydioxanone than that for any of the other sutures. These results seem to be attributable to the use of a relatively thick (USP 3-0) suture and long-term retention of the slowly absorbable monofilament Polydioxanone, resulting in protrusion of the two cut ends of the ligated suture into the peritoneal cavity even at 4 weeks and possibly causing mechanical injury of the surrounding tissue. Polydioxanone, which retains its tensile strength for a relatively long period, is suitable for use at sites where long-term preservation of the wound is needed (e.g., in cases of abdominal wall closure). The low incidence of severe adhesions observed for the absorbable monofilament Poliglecaprone 25 sutures can probably be explained by its rapid absorption and short duration of maintenance of the tensile strength [10].

The incidence of adhesions arising from the use of Polyglactin 910 is lower when a smaller-thickness suture was used under experimental conditions [19]. Laufer et al. [20] reported results contradictory to the current findings. They ligated the uterus with thin (UPS 6-0 and 8-0) Polydioxanone and Polyglactin 910. The incidence of adhesions was significantly higher for Polyglactin 910. Therefore, the incidence of adhesions may be reduced using thinner sutures. Sutures as thin as possible should be selected for use in the peritoneal cavity.

The incidence of abscess formation under contaminated conditions was higher with silk sutures, although it did not differ significantly from the incidence with the multifilament Polyglactin 910 sutures and the monofilament Polydioxanone and Poliglecaprone 25 sutures. A new type of Polyglactin 910 with its surface coated with the antimicrobial agent triclosan was recently launched in the market (Vicryl plus) although this was not available at the start of the present study. The incidence of infection is significantly lower with these sutures than with conventional Polyglactin 910 [21–23]. Although additional experiments are needed to endorse this finding, Vicryl plus is expected to be superior to conventional Vicryl in terms of resistance to infection, particularly when used for abdominal surgery under contaminated conditions.

Combining the results of the present study with the characteristics of sutures (e.g., ease of manipulation, such as knotting) endorses the use of multifilament absorbable sutures such as Vicryl as the optimal sutures for ligation and suturing within the peritoneal cavity even under contaminated conditions for preventing the formation of adhesions.

Conflict of interest The authors declare no conflict of interest.

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