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Efficacy and safety of purified starch for adhesion prevention in colorectal surgery

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ABSTRACT

Background: Adhesions within the abdominal cavity develop in as many as 90 % of individuals following abdominal surgery. However, the true adhesive condition of patients can only be ascertained during the second surgery.

Methods: We conducted a prospective, non-randomized study to assess the anti-adhesion properties of purified starch in patients who had undergone colorectal surgery in the past and then needed a subsequent surgical intervention. Adhesion scores have been prospectively recorded in operation notes since January 2020 when patients underwent a second surgery. Patients who had received purified starch during their initial surgery constituted the purified starch group, while those who had not received anti-adhesion medical materials were the control group. The main objectives of the study were to evaluate the extent and severity of adhesions as primary outcomes, while secondary outcomes included measuring blood loss, operation time, and postoperative complications.

Results: We analyzed the data of 101 patients, with 61 in the purified starch group and 40 in the control group. In multivariate analysis, adhesion severity (Odds ratio, 0.20, 95 % confidence interval 0.08–0.54, $P < 0.01$) and adhesion area scores (Odds ratio, 0.13, 95 % confidence interval 0.04–0.45, $P < 0.01$) were significantly lower in the purified starch group than in the control group. There was no significant difference in operation times, blood loss, and postoperative complications between the two groups.

Conclusion: Purified starch is a safe and effective anti-adhesion material that can significantly reduce the severity and extent of adhesion after colorectal surgery.

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1. Introduction

Adhesion formation commonly occurs after abdominal surgery; up to 90 % of patients experience adhesion formation after surgery [1,2]. Adhesions can lead to complications such as chronic abdominal pain, infertility, and bowel obstructions, which may require a second operation [3,4]. These complications increase the financial burden and hospitalization time for patients.

Various materials have been developed to reduce the formation of adhesions after abdominal surgery. These anti-adhesion materials encompass anti-inflammatory agents, antibiotics, fibrinolytic agents, solution barriers, and synthetic solid barriers [5–7]. They primarily work through two mechanisms: creating a barrier between adjacent organs to prevent adhesion formation and reducing local inflammatory responses within the abdominal cavity [8].

One novel adhesion product is derived from highly purified potato starch, which is transformed into a gel using a saline solution [9]. This gel acts as a barrier between traumatized peritoneal surfaces until the healing of the mesothelium is complete and is subsequently absorbed. Several studies have demonstrated the beneficial effects of this purified starch in preventing adhesion formation [9–12].

Numerous studies have proposed systems to standardize adhesion classification and quantification [13–16]. However, conducting studies to measure the efficacy of adhesion prevention measures is difficult because intra-abdominal adhesions can only be effectively assessed through direct observation through surgery or by analyzing patient symptoms or descriptions of their symptoms. Nevertheless, on rare occasions, patients agree to undergo a second surgery, which enables surgeons to analyze their intra-abdominal adhesion. Many patients who receive colorectal resection with temporary ostomy undergo re-operation to close the ostomy after a few months. Ostomy closure procedures provide a valuable opportunity to assess adhesions resulting from prior surgeries. Consequently, we carried out a prospective study to assess the effectiveness and safety of purified starch in preventing adhesions in colorectal surgery.

2. Materials and methods

2.1. Study design

This single center non-randomized prospective study among adults aged more than twenty was conducted to evaluate the anti-adhesion effect of purified potato starch product 4DryField® PH (PlantTec Medical GmbH, Bad Bevensen, Germany). Since January 2020, the Division of Colorectal Surgery at Taipei Medical University Shuang-Ho hospital has implemented a prospective requirement for surgeons to document the adhesion scores of abdominal cavities during the second surgery following colorectal resection. For this study, we collected data from patients who underwent their first colorectal surgery from January 2020 and data were obtained from the hospital's electronic medical records and surgical record database.

2.2. Inclusion and exclusion criteria

This study included patients who underwent a subsequent surgical procedure following colorectal resection. The usual interval between the first surgery and ostomy closure surgery was three to twelve months. Exclusions from the study comprised patients who had a second surgery within one month following their initial colorectal resection, those who exhibited peritoneal carcinomatosis during the second surgery, and patients under the age of twenty.

2.3. Intervention

The intervention group, referred to as the "purified starch group," consisted of patients who voluntarily chose to use purified starch at their own expense during their initial surgery. In contrast, the control group comprised patients who did not receive any anti-adhesion medical materials. In intervention group, 5 g of purified starch powder is mixed with 50 mL of 0.9 % saline solution to create a liquid gel, which is applied at the end of the surgery [10,16]. During open surgery, the premixed gel is poured directly into the abdominal cavity to ensure that it fully contacts the visceral peritoneum. During laparoscopic or robotic surgeries, the premixed gel is aspirated into a syringe and then directly applied to the visceral peritoneum via catheter.

2.4. Outcomes measurements

The characteristics of the first colorectal surgery and second surgery, including the surgical types, surgical procedures, operation times, blood loss, and postoperative complications, were recorded and analyzed. The main objectives of this study were to evaluate the severity and area of adhesions within the lower abdominal region. These measurements were obtained through direct visual examination of a laparotomy incision or laparoscopic inspection during second surgery. Adhesion severity and adhesion area were scored using a modified version of the peritoneal adhesion index [13–16]. Adhesion severity was classified into four grades: grade 0, indicating the absence of adhesion; grade I, signifying filmy adhesion that need blunt dissection only; grade II, representing strong adhesion that required sharp dissection; and grade III, denoting vascularized strong adhesion that necessitated careful dissection and were challenging to prevent damage. The adhesion area was also classified into four grades: grade 0, indicating the absence of adhesion; grade I, representing adhesion involving less than 1/3 area between the visceral organ and abdominal wall in the lower abdominal cavity; grade II, signifying adhesion covering between 1/3 and 2/3 of the area between the visceral organ and abdominal

wall in the lower abdominal cavity; and grade III, denoting adhesion extending over more than 2/3 of the area between the visceral organ and abdominal wall in the lower abdominal cavity. To ensure the objectivity of assessing adhesion scores, four attending physicians independently evaluated the severity and area of adhesions. During the scoring process, the assessors were not informed whether the patients had prior use of purified starch. This blinding was implemented to minimize any potential bias in the evaluation process. Secondary outcomes included measuring blood loss, operation time, and postoperative complications, including infection, anastomosis leakage, and abscess formation, in the second surgery.

2.5. Statistical analysis

The data were entered and analyzed using SPSS version 28.0 (IBM, Armonk, NY, USA). Quantitative variables were reported as means and standard deviations, while qualitative variables were presented as numbers. Group comparisons were conducted using Student's t-tests for continuous variables and chi-square tests for categorical variables. Odds ratios (ORs) were calculated by comparing the ratio of patients with an adhesion severity and area score ≥ 2 to those with a score <2, and the results were used to estimate the effect of various factors on adhesion severity and adhesion area. Univariate and multivariate regression analyses were performed to determine the ORs and 95 % confidence intervals (CIs) for several variables that could influence adhesion. All statistical tests were two-tailed, and a p-value of <0.05 was considered statistically significant.

2.6. Sample size

Based on prior research findings, our estimations indicate that the occurrence of adhesion severity or area score <2 is

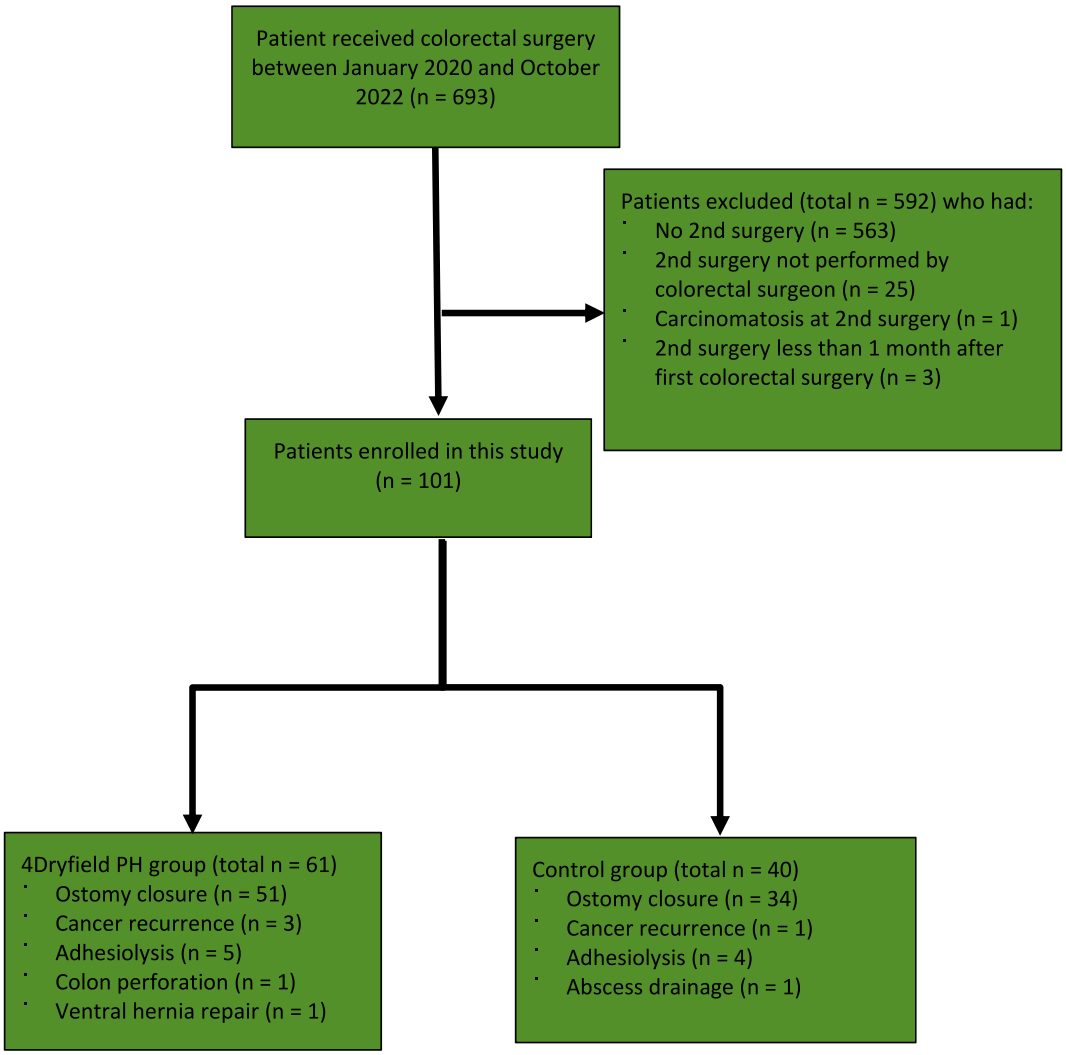

Fig. 1. Flowchart of patient exclusion and inclusion process.

approximately 50 % when utilizing purified starch, whereas it is around 20 % without the use of purified starch [9,10,17]. To ensure a statistical power of 80 % for detecting significant contrasts between groups using the Chi-square test, and maintaining a significance level of 5 %, a minimum of 38 participants per group are recommended to be included in the study.

3. Ethics approval and consent to participate

This study was conducted in accordance with the guidelines of the Declaration of Helsinki and data were reported following the recommendations of the STROCSS 2019 guideline [18]. All procedures involving participants were approved by the Joint Institutional Review Board and Ethics Committee (approval number: N202109018). The need for informed consent was waived by the Joint Institutional Review Board and Ethics Committee.

4. Results

Fig. 1 presents the flowchart of patient screening and selection process. Data from a total of 693 patients who underwent surgery between January 2020 and October 2022 were collected. Among the patient, 563 patients did not undergo a second surgery, 25 patients underwent a second surgery conducted by a non-colorectal surgeon, one patient had carcinomatosis in the second surgery, and

Table 1
Patient characteristics.

Characteristic	Purified starch group (61)	Control group (40)	*P* value
Age	61.5 ± 12.1	65.8 ± 15.2	0.12
Sex			0.08
Male	32	28	
Female	29	12	
Diagnosis			0.15
Colorectal cancer	44	33	
Sigmoid volvulus	0	1	
Colon perforation	14	5	
Colon inertia	0	1	
Colon benign tumor	3	0	
Malignancy			0.46
Stage I	10	11	
Stage II	12	5	
Stage III	11	12	
Stage IV	11	5	
History of previous operation	12	5	0.35
ASA score			0.77
I	4	3	
II	54	33	
III	2	4	
IV	1	0	
Surgery type			0.84
Robotic	5	5	
Laparoscopy	28	16	
Open surgery	28	19	
Surgical procedure			0.07
Right hemicolectomy	5	2	
Right Hemicolectomy + loop ileostomy	2	1	
Left hemicolectomy	2		
Anterior resection	2	3	
Anterior resection + loop transverse colostomy	37	27	
Hartmann procedure	9	6	
Abdominal perineal resection	2		
Subtotal colectomy		1	
Total colocolectomy + loop ileostomy	1		
Colon perforation repair + loop transverse colostomy	1		
1st operation time (min)	201 ± 85	190 ± 81	0.51
1st operation bleeding (mL)	118 ± 177	178 ± 330	0.24
Complications in 1st surgery			
Surgical infection	0	0	–
Anastomosis leakage	0	1	0.40
Intra-abdominal abscess	0	1	0.40
Comorbidity			
Liver disease	1	3	0.14
Diabetes	9	14	**0.03**
Cardiovedcular disease	1	4	0.06

Note. Values are presented as means ± standard deviations. Bold values indicate significance ($P < 0.05$).
ASA, American Society of Anesthesiology.

3 patients had a second surgery less than 1 month after the first colorectal surgery. The data of the remaining 101 patients were analyzed in this study. For 61 patients, purified starch was applied as adhesion prevention. Among these patients, 51, 3, 5, 1, and 1 received reoperation for ostomy closure, cancer recurrence, adhesiolysis, colon perforation, and ventral hernia repair, respectively. For 40 patients, purified starch was not applied as adhesion prevention. These patients were assigned to the control group. Among this group, 34, 1, 4, and 1 patients received reoperation for ostomy closure, cancer recurrence, adhesiolysis, and abscess drainage, respectively.

4.1. Patient characteristics

The demographic characteristics of patients are detailed in Table 1. The mean age (± standard deviation) of the purified starch and control groups was 61.5 ± 12.1 and 65.8 ± 15.2, respectively ($P = 0.12$). Most patients were hospitalized for colorectal cancer, and they mainly received low anterior resection or anterior resection with temporary ostomy. No significant differences were noted in first colorectal surgery between the groups except for the number of patients with diabetes ($P = 0.03$).

4.2. Adhesion severity and adhesion area

The adhesion severity and adhesion area scores of the purified starch and control groups are listed in Table 2. We determined the numbers of patients in each score group. The numbers of patients in the purified starch and control groups were 13 and 3 in the grade 0, 27 and 12 in the grade I, 18 and 20 in the grade II, and 3 and 5 in the grade III groups, respectively. For adhesion area scores, the numbers of patients in the purified starch and control groups were 13 and 3 in the grade 0, 33 and 17 in the grade I, 8 and 10 in the grade II, and 7 and 10 in the grade III groups, respectively. The purified starch group had significantly lower adhesion severity ($P < 0.01$) and smaller adhesion area ($P < 0.01$) than the control group did.

The second surgery characteristics of the purified starch and control groups are also listed in Table 2. The mean operation time was 104 ± 64 min in the purified starch group and 95 ± 49 min in the control group ($P = 0.43$). The mean blood loss was 55 ± 198 mL in the purified starch group and 19 ± 50 mL in the control group ($P = 0.26$). Regarding postoperative complications, one patient in the control group had an intra-abdominal abscess after the first colorectal surgery the other one patient had anastomotic leakage after the first colorectal surgery. No significant differences in complications were identified between the groups.

4.3. Univariate and multivariate analysis of adhesion severity

In Table 3, we demonstrated the risks of adhesion severity by univariate and multivariate analysis. In univariate analysis, only using purified starch reduced adhesion severity, with an ORs of 0.31 (95 % CI: 0.14 to 0.72, $P < 0.01$). In multivariate analysis, using purified

Table 2
Second surgery adhesion scores and characteristics between the groups.

	Purified starch group (61)	Control group (40)	*P* value
Adhesion severity score			**<0.01**
0	13	3	
I	27	12	
II	18	20	
III	3	5	
Adhesion area score			**<0.01**
0	13	3	
I	33	17	
II	8	10	
III	7	10	
2nd Surgical procedure			0.74
Stomy closure	51	34	
Loop transverse colostomy	39	27	
Loop Ileostomy	3	1	
End Colostomy	9	6	
Tumor excision	3	1	
Adhesiolysis	5	4	
Diverticulitis perforation	1		
Abscess drainage		1	
Ventral hernia repair	1		
2nd operation time (min)	104 ± 64	95 ± 49	0.43
2nd operation bleeding (mL)	55 ± 198	19 ± 50	0.26
Interval between 1st surgery and 2nd surgery (day)	155 ± 117	177 ± 130	0.58
Complications in 2nd operation			
Wound infection	2	0	0.25
Anastomosis leakage	0	0	0.99
Intra-abdominal abscess	1	0	0.42

Note. Values are presented as means ± standard deviations. Bold values indicate significance ($P < 0.05$).

starch was identified as a factor affecting adhesion severity, with an ORs of 0.20 (95 % CI: 0.08 to 0.54, $P < 0.01$). The other factor affecting adhesion severity was diabetes, with an ORs of 0.27 (95 % CI: 0.08 to 0.86, $P = 0.03$). There was no significant difference in adhesion severity on age, sex, diagnosis, previous operation history, ASA score, surgical type, surgical procedure, operation time, blood loss, and comorbidity of liver or cardiovascular disease in univariate and multivariate analysis.

4.4. Univariate and multivariate analysis of adhesion area

In Table 4, we demonstrated the risks of adhesion area by univariate and multivariate analysis. In the univariate analysis, using purified starch reduced adhesion area, with an OR of 0.33 (95 % CI: 0.14 to 0.76, $P = 0.01$). Laparoscopic led to smaller adhesion area than open surgery, with OR of 0.14 (95 % CI: 0.05 to 0.38, $P < 0.01$). Furthermore, colon perforation was more likely to occur in patients with increased adhesion area compared with those with colorectal cancer, with an OR of 3.85 (95 % CI: 1.36 to 10.94, $P = 0.01$). Patients who underwent Hartmann procedures were more likely to have increased adhesion areas than those who underwent anterior resection, with an OR of 9.11 (95 % CI: 2.55 to 32.56, $P < 0.01$). Patients with colon cancer in stages I-II and stages III-IV exhibited smaller adhesion areas compared to those with benign colon disease. The OR was 0.18 (95 % CI: 0.06 to 0.56, $P < 0.01$) for stages I-II and 0.30 (95 % CI: 0.10 to 0.85, $P < 0.01$) for stages III-IV. First operation time more than 2 h was more likely to increase adhesion area than operation time less than 2 h, with an OR of 0.27 (95 % CI: 0.10 to 0.70, $P < 0.01$). The other characteristics were not significantly associated with adhesion area.

Table 3
Univariate and multivariate analysis of adhesion severity.

Characteristics	Unadjusted analysis		Adjusted analysis	
	Odd ratio (95 % CI)	*p* value	Odd ratio (95 % CI)	*p* value
Purified starch used				
Control group	1		1	
Purified starch group	0.31 (0.14–0.72)	<**0.01**[a]	0.2 (0.08–0.54)	**0.02**
Sex				
Male	1			
Female	0.76 (0.34–1.67)	0.50		
Age				
Age ≥65	1			
Age <65	1.18 (0.54–2.61)	0.68		
ASA score				
ASA 1-2	1			
ASA ≥3	0.46 (0.08–2.46)	0.36		
Diagnosis				
Colorectal cancer	1			
Colon perforation	0.68 (0.24–1.93)	0.47		
Colon benign lesion	2.34 (0.41–13.57)	0.34	1	
Comorbidity				
No comorbidity	1			
Liver disease	1.20 (0.16–8.90)	0.86		
Diabetes	0.40 (0.15–1.08)	0.07[a]	0.27 (0.08–0.86)	**0.03**
Cardiovascular disease	0.79 (0.13–4.93)	0.80	1	
History of previous abdominal surgery				
No	1			
Yes	2.57 (0.87–7.60)	0.09[a]	2.93 (0.90–9.54)	0.07
Tumor stage				
Benign	1			
Stage I-II	1.08 (0.39–3.00)	0.88		
Stage III-IV	1.09 (0.40–3.00)	0.87		
Surgery type				
Open surgery	1		1	
Laparoscopy	0.46 (0.20–1.06)	0.07[a]	0.60 (0.24–1.52)	0.28
Robotic	1.32 (0.33–5.29)	0.70	1.90 (0.38–9.46)	0.43
Surgical procedure				
Anterior resection	1			
Hemicolectomy	0.65 (0.18–2.36)	0.51		
Hartmann procedure	1.95 (0.63–6.08)	0.25		
Operation time				
<120 min	1			
≥120 min	0.64 (0.25–1.59)	0.33		
Blood loss				
<200 ml	1			
≥200 ml	1.91 (0.66–5.49)	0.23		

Note. Bold values indicate significance ($P < 0.05$).
[a]Only variables with $p < 0.2$ in univariate analysis were included to multivariate analysis.
OR, odds ratio; CI, confidence interval; ASA, American Society of Anesthesiology.

Table 4
Univariate and multivariate analysis of adhesion area.

Characteristics	Unadjusted analysis		Adjusted analysis	
	Odd ratio (95 % CI)	*p* value	Odd ratio (95 % CI)	*p* value
Purified starch used				
Control group	1		1	
Purified starch group	0.33 (0.14–0.76)	**0.01**[a]	0.12 (0.03–0.45)	<**0.01**
Sex				
Male	1			
Female	0.80 (0.35–1.86)	0.61		
Age				
Age ≥65	1			
Age <65	0.73 (0.32–1.67)	0.46		
ASA score				
ASA 1-2	1			
ASA ≥3	1.45 (0.31–6.89)	0.64		
Diagnosis				
Colorectal cancer	1		1	
Colon perforation	3.85 (1.36–10.94)	**0.01**[a]	10.19 (0.68–129.33)	0.10
Colon benign lesion	5.60 (0.95–32.96)	0.06[a]	0.91 (0.18–4.59)	0.91
Comorbidity				
No comorbidity	1			
Liver disease	0.62 (0.06–6.17)	0.68		
Diabetes	0.55 (0.20–1.55)	0.26		
Cardiovascular disease	1.27 (0.20–8.00)	0.80		
History of previous abdominal surgery				
No	1			
Yes	1.88 (0.65–5.34)	0.24		
Tumor stage				
Benign	1		1	
Stage I-II	0.18 (0.06–0.56)	**<0.01**[a]	0.09 (0.01–1.31)	0.08
Stage III-IV	0.30 (0.10–0.85)	**0.02**[a]	0.11 (0.01–1.48)	0.10
Surgery type				
Open surgery	1		1	
Laparoscopy	0.14 (0.05–0.38)	**<0.01**[a]	0.09 (0.02–0.44)	**0.02**
Robotic	0.08 (0.01–0.70)	**0.02**[a]	0.09 (0.01–1.05)	0.06
Surgical procedure				
Anterior resection	1		1	
Hemicolectomy	1.66 (0.44–6.23)	0.46	1.09 (0.18–6.48)	0.93
Hartmann procedure	9.11 (2.55–32.56)	**<0.01**[a]	3.50 (0.58–21.20)	0.17
Operation time				
<120 min	1		1	
≥120 min	0.27 (0.10–0.70)	**<0.01**[a]	0.54 (0.14–2.02)	0.36
Blood loss				
<200 ml	1			
≥200 ml	1.88 (0.65–5.34)	0.24		

Note. Bold values indicate significance ($P < 0.05$).
[a]Only variables with $p < 0.2$ in univariate analysis were included to multivariate analysis.
OR, odds ratio; CI, confidence interval; ASA, American Society of Anesthesiology.

In the multivariate analysis, using purified starch was identified as a factor affecting adhesion area, with an OR of 0.13 (95 % CI: 0.04 to 0.45, $P < 0.01$). The other factor affecting adhesion area was laparoscopic surgery with an OR of 0.09 (95 % CI: 0.02 to 0.43, $P = 0.02$). There was no significant difference in adhesion area on age, sex, previous operation history, ASA score, blood loss, cancer staging, and comorbidity.

5. Discussion

In colorectal surgery, temporary stoma is often required for various reasons in elective or emergency surgery. Patients who receive a temporary stoma may undergo a second surgery to close the stoma. Therefore, avoiding adhesion is important to reduce the difficulty in second operation. Many researchers conducting studies on postoperative intra-abdominal adhesion use the stoma closure as an opportunity to observe and evaluate adhesion severity and adhesion area [5]. However, these studies have mainly focused on the anti-adhesion effects of hyaluronic acid–based membranes, 4 % icodextrin, or polylactic acid membranes. To the best of our knowledge, this is the first study to evaluate the anti-adhesion effects of purified starch in colorectal surgery. This study demonstrated that purified starch had anti-adhesion effects in colorectal surgery. The severity and extent of adhesion were significantly reduced by using purified starch, and the postoperative complications for the first and second operations did not differ between the purified starch group and control groups.

Because anti-adhesion products are non-essential for surgery and are foreign bodies to the human body, the most crucial factor that

surgeons should consider when selecting anti-adhesion products is preventing unnecessary or unexpected complications. The hyaluronic acid carboxymethylcellulose membrane (Seprafilm, Genzyme, USA) has been the most studied anti-adhesion product for colorectal surgery. In many randomized control studies, Seprafilm was reported to reduce the incidence of adhesion and reduce adhesion severity and extent after colorectal surgery [19–22]. Several studies have demonstrated that using Seprafilm can reduce the operation time of the second surgery, particularly for ostomy closure surgery [23]. However, using Seprafilm in colorectal surgery could increase the incidence of anastomotic leakage and intra-abdominal abscess [19]. In a systematic review, Hajibandeh et al. revealed that Seprafilm significantly increased the anastomotic leakage rate in colorectal surgery [24]. Icodextrin solution is another anti-adhesion material that has been frequently used. A randomized control trial involving 181 patients demonstrated that the incidence of small bowel adhesion obstruction was reduced when 4 % icodextrin was used in colorectal surgery [25]. In addition, Kossi et al. reported that the dissection time in stoma closure procedures was reduced when 4 % icodextrin was used during a patient's first Hartmann operation [26]. However, Lee et al. revealed that using 4 % icodextrin in colorectal surgery led to a higher incidence of small bowel obstruction compared with not using any anti-adhesion materials [27]. Severe small bowel serosal fibrosis and dense adhesion were also reported in patients in whom 4 % icodextrin was used in abdominal surgery [28,29]. Polylactide has also been reported as a promising anti-adhesion material, and using polylactide film in hepatobiliary surgery was reported to reduce the incidence of postoperative ileus [30]. Placing the film around the stoma during colorectal surgery was reported to reduce adhesion severity and shorten the operation time during stoma closure [31]. However, the average degradation time of polylactide film is 12 weeks [8], and some patients exhibited severe foreign body reactions, with the polylactide film mimicking local tumor recurrence after abdominal surgery [32,33]. In this study, the use of purified starch did not result in an increased incidence of postoperative complications, including anastomotic leakage and surgical site infection. However, to further validate these findings, it is necessary to conduct additional studies with larger sample sizes and long-term follow-up.

In the present study, using purified starch in colorectal surgery was discovered to be safe and effective. Compared with the control group, the purified starch group demonstrated no increase in allergies, foreign body reactions, and surgery-related anastomotic leakage. Postoperative adhesion is associated with mesothelial cell healing, which generally occurs 3–5 days after surgery [34]. The purified starch attaches to the visceral organ and is resorbed by amylases within 7 postoperative days [9], thus the barrier formed by this purified starch on the traumatic wound has sufficient time to block adhesion formation. Furthermore, this purified starch does not cause adverse foreign body reactions or local inflammation resulting from slow degradation. In addition, film-like anti-adhesion products are difficult to apply and fit between the interloops of the bowels and the pelvic cavity, and are also challenging to put into the abdominal cavity through a trocar in laparoscopic surgery. By comparison, the premixed starch gel is convenient to use. Surgeons can simply pour or infuse premixed starch gel directly into the abdominal cavity and can achieve adhesion prevention by ensuring that the gel makes full contact and coats the wound and the surface of the visceral organ.

Numerous studies have demonstrated shortened stoma closure operation time when anti-adhesion products were applied in the first colorectal surgery [23,26,31]. In our study, although adhesion severity and adhesion area were reduced when purified starch was used, the second surgery operation time did not significantly differ between the purified starch group and control groups. This was mainly because not all of the second surgeries in our study were stoma closure surgeries. Moreover, the stoma closures in this study included loop stoma closures and reverse Hartmann operations, which may explain why the operation times did not differ between the groups.

Minimally invasive surgeries, such as laparoscopic or robotic surgeries, can reduce adhesion area because they create smaller wounds [35] and minimize visceral organ mobilization than open surgery. However, the tissue damage caused by energy devices, such as electrocauterization in laparoscopic or conventional open surgeries, does not differ. Therefore, in our study, adhesion severity was not different between open surgery and minimal invasive surgery. To reduce adhesion formation in laparoscopic surgery, 5 % N_2O, 4 % O_2 or both can be added to CO_2 during creation of the pneumoperitoneum. This would prevent mesothelial cell hypoxia and minimize acute inflammation [36–38]. Adhesion formation can also be prevented by using a barrier to prevent desiccation and to reduce pure CO_2–related hypoxia irritation [38]. Our study demonstrated that the barrier formed by coating this purified starch gel on the traumatized area and visceral organ can fully moisturize the surface and prevent contact with humoral inflammatory factors and thereby reduce postoperative adhesion.

This study also found that diabetes reduced the adhesion severity in patients with colorectal surgery. The relationship between diabetes and intra-abdominal adhesions is still inconclusive, and there is a lack of research and investigation about intra-abdominal adhesion in diabetes patients. In some studies, hyperglycemia has been found to increase intercellular collagen and inhibit collagen hydrolysis. This causes a large amount of collagen deposition in the intercellular matrix, leading to increased tissue fibrosis [39,40]. Another study found that hyperglycemia can also cause peritoneal fibroblast dysfunction, which stimulate its proliferation and produce collagen, resulting in tissue fibrosis [41]. On the other hand, diabetes can also cause tissue hypoxia, increase the concentration of ROS, increase production of metalloproteases in extracellular matrix, and reduce angiogenesis and neovascularization, which reduces the generation of adhesion [42]. Therefore, the effect of diabetes on intra-abdominal adhesion still needs to be further studied.

This study has several limitations. First, the total sample size was small, and there was a significant disparity in the number of patients undergoing robotic surgery compared to those undergoing open or laparoscopic surgery. This imbalance may have introduced bias into our data analysis. Second, this study was not a randomized controlled trial. However, the detailed records of adhesion status included in the patients' surgical records allowed us to conduct this study. Third, our assessment only focused on the severity and extent score of adhesions, and certain symptoms related to adhesion ileus, such as abdominal fullness, pain, and constipation, may not have manifested during the relatively short follow-up period. Nonetheless, reoperation provided a reliable method to evaluate the preventive effect of purified starch on adhesion severity and extent. Thus, we believe our study can offer valuable evidence in this area. Fourth, adhesion status was recorded only for patients who underwent surgery performed by the colorectal surgeons at our institution.

Consequently, patients who had their second operation performed by other surgeons were not included, potentially introducing bias. Finally, the time period between the first and second operations was approximately six months. During this interval, various confounding factors including the presence of other abdominal diseases, administration of chemotherapy, and dietary changes may have influenced the adhesion scores and potentially introduced biases into the study findings.

In conclusion, the present study revealed that purified starch reduced both adhesion severity and adhesion area in colorectal surgery. Furthermore, using purified starch in colorectal surgery did not increase the incidence of complications. This study holds a significant position as a pioneering investigation into the anti-adhesion properties of purified starch in the realm of colorectal surgery. A randomized controlled trial including more patients would lead to more robust conclusions.

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Availability of data and materials

The datasets used in this study can be obtained from the corresponding author upon reasonable request.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Tzu-Min Liu: Data curation, Formal analysis, Investigation, Software, Writing – original draft, Project administration. **Kee-Thai Kiu:** Data curation, Investigation, Supervision. **Min-Hsuan Yen:** Data curation, Investigation, Supervision. **Ka-Wai Tam:** Methodology, Supervision, Writing – review & editing. **Tung-Cheng Chang:** Conceptualization, Formal analysis, Project administration, Supervision, Validation, Writing – review & editing, Data curation.

Declaration of competing interest

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

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