Risk factors for periappendiceal adhesions in acute appendicitis: a retrospective comparative study

Shenshuo Gao¹, Xiaobo Guo², Leping Li², Changqing Jing² and Yan Ma²*

Abstract
Purpose: Acute appendicitis usually requires immediate surgical treatment, but appendectomies were difficult for some patients with severe periappendiceal adhesions. We investigated risk factors of intraoperative adhesions to help surgeons make better treatment plans for appendicitis.

Methods: We retrospectively analyzed 186 cases diagnosed with acute appendicitis and underwent surgery in Shandong Provincial Hospital affiliated to Shandong First Medical University between January 2018 and December 2019. According to the degree of intraoperative adhesions, they were divided into mild, moderate and severe groups. Then, we analyzed a number of preoperative factors contributed to adhesions, suppuration and perforation during appendectomy in 186 patients.

Results: Contrast to the moderate group (MoG) and the mild group (MiG), the severe degree of adhesions group (SG) had a higher intraoperative perforation and suppuration rate, a greater likelihood of conversion to open and more postoperative complications. Multivariable logistic regression analysis showed that recurrent appendicitis and high neutrophil percentage were independently associated with periappendiceal adhesions. The preoperative ultrasonography (US) revealed periappendiceal fluid and high neutrophil percentage were independently associated with appendix suppuration. A high preoperative neutrophil percentage was independently associated with appendix perforation.

Conclusions: Recurrent appendicitis and preoperative high neutrophil percentage were risk factors of periappendiceal adhesions; preoperative US revealed periappendiceal fluid and high neutrophil percentage were risk factors of appendix suppuration; and a high preoperative neutrophil percentage was a risk factor of appendix perforation.

Keywords: Appendectomy, Adhesions, Risk factors, Perforation, Suppuration

Introduction
Appendicitis is a global disease. The incidence of appendicitis is stable in most Western countries. But data from newly industrialized countries suggests that appendicitis is rising rapidly [1]. Appendicitis has a high incidence and is one of the most common diseases in abdominal emergency. Although some studies suggested that antibiotic treatment can cure acute appendicitis or can be the first line of treatment [2–5], appendectomy is still the main surgical method for the treatment of appendicitis. Current evidence shows laparoscopic appendectomy (LA) was the most effective surgical treatment, being associated with a lower incidence of wound infection, lower pain intensity on day one, shorter hospital stay, earlier food tolerance, earlier return to work and better

*Correspondence: mayan.18@163.com
2 Department of Gastroenterological Surgery, Shandong Provincial Hospital Affiliated to Shandong First Medical University, Jinan 250021, Shandong, China
Full list of author information is available at the end of the article
quality of life scores when compared to open appendectomy (OA) [6–9]. Though the majority of patients with acute appendicitis can be successfully managed with laparoscopy, some operations were initiated laparoscopically but were converted to the open approach because of technical limitations, body habitus, prior surgery, more advanced disease, or surgical inexperience [10, 11]. The conversion to open rate during laparoscopic appendectomy is ~4% [12]. It had a higher likelihood of complications compared to OA [10]. The most common reason for open conversion were severe acute inflammation and adhesions [13]. Obviously, severe acute inflammation and adhesions can make appendectomy more difficult and even cause more complications. The aim of our study is to evaluate preoperative risk factors that are contributed to adhesions and suppuration in LA and OA, and to help surgeons make better decision before operations.

Methods
We retrospectively analyzed 186 cases diagnosed with acute appendicitis and underwent surgery in Shandong Provincial Hospital affiliated to Shandong First Medical University between January 2018 and December 2019, including 144 cases with LA and 42 cases with OA. Exclusion criteria include: non-operative treatment cases, cases with previous history of major abdominal surgery, cases with unclear intraoperative adhesions degree, cases with postoperative pathological confirmation of appendiceal tumor, and cases younger than 14 years old. All the data were obtained from the patients’ medical records, and the study was approved by the ethics committee of the study center.

This study collected and analyzed the information of patients including age, gender, whether the first onset of appendicitis, time interval from symptom onset to operation, time interval from initial symptom onset to operation of recurrent cases, preoperative leukocyte count and neutrophil percentage within 24 h, whether preoperative ultrasonography(US) revealed periappendiceal fluid, the operation time, the degree of periappendiceal adhesions, appendix situation of perforation, appendix situation of suppuration, whether extended resection, whether conversion to open surgery, postoperative complications, total length of hospital stay.

The patients who were not clearly diagnosed with appendicitis before this hospitalization were the first onset, and the others were recurrent. For all surgical patients, time interval from symptom onset to operation was divided into four groups: ≤ 1 day (group A), > 1 day and ≤ 2 days (group B), > 2 days and ≤ 3 days (group C), and > 3 days (group D). For recurrent patients, time interval from initial symptom onset to operation was divided into three groups: ≤ 3 months (group E), > 3 months and ≤ 12 months (group F), and > 12 months (group G). Whether perforation, suppuration or convert to open during surgery is according to medical records. Extended resection including partial cecectomy, right hemicolecctomy or partial small bowel resection. Postoperative complications mainly include within 30 days of postoperative incision infection, incision hernia, intestinal obstruction, abdominal abscess, pulmonary infection, lower limb vein thrombosis and so on.

According to the description of the surgical records, the appendiceal adhesion extent was classified into three degrees [14]: mild (no obvious adhesion or light adhesions, which can easily be separated by blunt dissection), moderate (adhesions where blunt dissection is possible but sharp dissection necessary, with vascularization), and severe (lysis of the adhesions is possible by sharp dissection only, organs are strongly attached, and organ damage is hard to prevent). Intraoperative details and early postoperative outcomes were compared between three groups, and Univariate and multivariate analyses were used to study the risk factors of intraoperative adhesions, suppuration, and perforation.

Statistical analysis
All analyses were performed using IBM SPSS Statistics for Windows version 25 (IBM Corp., Armonk, NY, USA). Mann–Whitney U test or Kruskal–Wallis H test were used for non-normally distributed continuous variables, which were shown as the median and range. Categorical variables were analyzed using the χ2 test or Fisher’s exact test. Multivariable logistic regression was performed to identify independent risk factors associated with intraoperative adhesions, suppuration and perforation during appendectomy, and the results expressed as odds ratios (ORs) and 95% confidence intervals (95% CIs). P values of <0.05 were considered statistically significant.

Results
Patients' demographics and clinical characteristics
Among the 186 cases of appendectomy patients included in the analysis, 89 were male and 97 were female, 118 were the first onset and 68 were recurrent, 144 patients underwent LA and 42 patients underwent OA. Groups of time interval from symptom onset to operation are as follows: group A 64, group B 58, group C 22, group D 36, and 6 patients that onset time were not clearly record. Recurrent groups of time interval from initial symptom onset to operation are as follows: group E 9, group F 25, group G 29, and 5 patients that onset time were not clearly record. 35 cases were found to have periappendiceal fluid by preoperative US examinations, 147 cases were not, and 4 cases had no preoperative US examination. There were 103 cases of
suppuration and 83 cases of non-suppuration. There were 92 cases with mild, 34 cases with moderate and 60 cases with severe abdominal adhesions. 27 cases were found to have perforated appendix. The average operation time was 76 min. The preoperative WBC count was 11.4 (range from 2.1 to 24.3) and the preoperative neutrophil percentage was 74.6 (range from 30.5 to 95.8). 115 cases were placed a drainage tube in abdominal cavity in the end of operation. Table 1 shows 186 patients’ characteristics.

Table 2 shows the intraoperative details and early postoperative outcomes of the three groups with different degrees of adhesions. Contrast to the moderate group (MoG) and the mild group (MiG), the severe degree of adhesions group (SG) has a longer operation time (mean: 98.6 vs. 71.5 vs. 62.8 min, \( P < 0.001 \)), longer postoperative hospital stay (mean: 5.7 vs. 4.3 vs. 3.7 days, \( P = 0.002 \)), higher intraoperative suppuration rate (66.7 vs. 64.7 vs. 44.6%, \( P = 0.013 \)), higher intraoperative perforation rate (26.7 vs. 26.5 vs. 2.2%, \( P < 0.001 \)), a greater likelihood of conversion to open (25.9 vs. 0 vs. 0%, \( P < 0.001 \)), and more postoperative complications (10.0 vs. 8.8 vs. 1.1%, \( P = 0.036 \)). All these differences between three groups are significant.

### Multivariate analysis

Table 3 shows a comparison of preoperative factors among three groups of patients (MoG, MiG and SG) with different degrees of adhesions during appendectomy. The gender and age of three groups were not significantly different (\( P = 0.475 \), \( P = 0.063 \) respectively). Time interval from symptom onset to operation of three groups were not significantly different (\( P = 0.361 \)). The severe degree of adhesions group (SG) has a higher neutrophil percentage than other groups (MoG and MiG) (mean: 78.2 vs. 78 vs. 71%, \( P = 0.015 \)). However, preoperative leukocyte count of three groups was not significantly different (\( P = 0.106 \)). The severe degree of adhesions group (SG) has a higher rate of preoperative US revealed periappendiceal fluid than other groups (MoG and MiG) (28.8 vs. 23.5 vs. 11.2%, \( P = 0.023 \)). Multivariable logistic regression analysis showed that the recurrent appendicitis (OR 95% CI 0.119, 1.589, \( P = 0.023 \)) and high neutrophil percentage (OR 95% CI 0.014, 0.079, \( P = 0.005 \)) were independently associated with the degree of appendiceal adhesions.

Table 4 shows a comparison of preoperative factors among three groups of patients (MoG, MiG and SG) with different degrees of adhesions in the recurrent

### Table 1 Clinical characteristics of 186 cases with appendectomy

| Clinical characteristics | Number of cases (proportion, %) |
|--------------------------|---------------------------------|
| Gender, male/female      | 89 (47.8%)/ 97 (52.2%)          |
| Age, < 40 / ≥ 40 years   | 101 (54.3%)/ 85 (45.7%)         |
| Operation, LA/OA         | 155 (83.3%)/ 31 (16.7%)         |
| First onset, yes/no      | 118 (63.4%)/ 68 (36.6%)         |
| Time interval from the onset to operation, days |
| ≤ 1                      | 6 no record                     |
| 1 < and ≤ 2              | 64 (34.4%)                      |
| 2 < and ≤ 3              | 58 (31.2%)                      |
| > 3                      | 22 (11.8%)                      |
| Time interval from initial onset to operation of recurrent patients, months |
| ≤ 3                      | 9 (14.3%)                       |
| 3 < and ≤ 12             | 25 (39.7%)                      |
| > 12                     | 29 (46.0%)                      |
| Degree of intraoperative adhesions mild/middle/severe | 92 (49.5%)/ 34 (18.3%)/ 60 (32.2%) |
| Intraoperative suppuration, yes/no | 103 (55.4%)/ 83 (44.6%) |
| Intraoperative appendiceal perforation, yes/no | 27 (14.5%)/ 159 (85.5%) |
| Operative time, mins     | 76 (20, 190)                    |
| Preoperative leukocyte count, × 10^9/L | 114 (2.1, 24.3) |
| Preoperative neutrophil percentage | 74.6% (30.5%, 95.8%) |
| Preoperative US revealed periappendiceal fluid, yes/no | 4 no record |
| Drainage tube, yes/no    | 115 (61.8%)/ 71 (38.2%)         |
| Pathology results, suppurative/ non-suppurative appendicitis | 108 (58.1%)/ 78 (41.9%) |

LA laparoscopic appendectomy, OA open appendectomy, US ultrasonography
Table 2  Comparison of clinical characteristics of patients with different degrees of adhesions during appendectomy

| Degree of intraoperative adhesions | H /χ² value | P value |
|------------------------------------|-------------|---------|
| Inpatient days, days               |             |         |
| Mild                               | 3.7 (1, 10) |         |
| Middle                             | 4.3 (1, 10) |         |
| Severe                             | 5.7 (1, 43) |         |
| Intraoperative suppuration         |             |         |
| Yes                                | 41          | 12.136  |
| No                                 | 51          | 0.002*  |
| Intraoperative appendiceal perforation |       |         |
| Yes                                | 2           | 25.181  |
| No                                 | 90          | <0.001* |
| Operative time, mins               |             |         |
| 62.8 (20, 130)                     | 6.581       | 0.361   |
| 71.5 (30, 130)                     | 5.526       | 0.063   |
| 98.6 (35, 190)                     | 4.487       | 0.310   |
| LA conversion to OA                |             |         |
| Yes                                | 0           | 27.764  |
| No                                 | 75          | <0.001* |
| Extended resection                 |             |         |
| Yes                                | 1           | 2.590   |
| No                                 | 91          | 0.310   |
| Complications                      |             |         |
| Yes                                | 1           | 7.283   |
| No                                 | 91          | 0.015*  |

LA laparoscopic appendectomy, OA open appendectomy, OR odds ratio, CI confidence interval
*P value is statistically significant

Table 3  Risk factors of adhesions during appendectomy identified by univariate and multivariate logistic regression analysis

| Univariate analysis | Multivariate analysis |
|---------------------|-----------------------|
|                     | Degree of intraoperative adhesions | H /χ² value | P value | OR (95%CI) | P value |
|                     | Mild | Middle | Severe |             |         |         |         |
| Gender              |      |        |        |             |         |         |         |
| Male                | 40   | 17     | 32     | 1.491       | 0.475   | -0.249, 0.956 | 0.250 |
| Female              | 52   | 17     | 28     |             |         | Reference |         |
| Age, years          |      |        |        |             |         |         |         |
| 37.5 (14 ~ 78)      | 35   | 10     | 23     | 0.918       | 0.632   | 0.119, 1.589 | 0.023* |
| First onset         |      |        |        |             |         | Reference |         |
| No                  | 35   | 10     | 23     |             |         |         |         |
| Yes                 | 57   | 24     | 37     |             |         |         |         |
| Time interval from on-set to operation, days |      |        |        |             |         |         |         |
| ≤ 1                 | 34   | 8      | 22     | 6.581       | 0.361   | -1.063, 0.879 | 0.253 |
| 1 < and ≤ 2         | 24   | 15     | 19     |             |         | -0.717, 1.193 | 0.626 |
| 2 < and ≤ 3         | 8    | 5      | 9      |             |         | -0.664, 1.618 | 0.412 |
| > 3                 | 21   | 6      | 9      |             |         | Reference |         |
| Preoperative leukocyte count, x 10⁹/L |      |        |        |             |         |         |         |
| 10.6 (2.1 ~ 22.5)   | 10.6 | 13.1   | 11.7   | 4.487       | 0.106   | -0.090, 0.062 | 0.717 |
| Preoperative neutrophil percentage, % |      |        |        |             |         | 0.014, 0.079 | 0.005* |
| 71 (30.5 ~ 95.8)    | 71   | 78     | 78.2   |             |         | Reference |         |
| Preoperative US revealed periappendiceal fluid |      |        |        |             |         |         |         |
| No                  | 79   | 26     | 42     | 7.555       | 0.023*  | -1.389, 0.168 | 0.012 |
| Yes                 | 10   | 8      | 17     |             |         | Reference |         |

OR odds ratio, CI confidence interval, US ultrasonography
*P value is statistically significant
appendicitis. Time interval from initial symptom onset to operation of three groups were not significantly different ($P = 0.778$). The gender, age, preoperative leukocyte count, preoperative US revealed periappendiceal fluid in three groups were all not significantly different ($P = 0.361$, $P = 0.915$, $P = 0.488$, $P = 0.198$ respectively).

Although the severe degree of adhesions group (SG) has a higher neutrophil percentage than other groups (MoG and MiG) (mean: 73.7 vs. 61.9 vs. 63.7%, $P = 0.010$), multivariable logistic regression analysis showed that none of above were significant risk factors.

Table 5 shows a comparison of preoperative factors between suppurative and non-suppurative patients during appendectomy. The gender between two groups was not significantly different ($P = 0.164$). The age between the suppurative group and non-suppurative group was significantly different (mean: 42.4 vs. 37.5, $P = 0.040$). The proportion of the first onset between two groups was significantly different ($P < 0.001$). Time interval from symptom onset to operation of two groups was significantly different ($P < 0.001$). The preoperative leukocyte count and neutrophil percentage between the suppurative group and non-suppurative group were significantly different (mean: 14.8 vs. $8.8 \times 10^9/L$, $P < 0.001$ and 82.5 vs. 64.7%, $P < 0.001$). The proportion of preoperative US revealed periappendiceal fluid between two groups was significantly different (31.0 vs. 4.9%, $P < 0.001$). Multivariable logistic regression analysis showed that only the preoperative US revealed periappendiceal fluid (OR 0.138, 95% CI 0.034, 0.561, $P = 0.006$) and high neutrophil percentage (OR 1.109, 95% CI 1.051, 1.169, $P < 0.001$) were independently associated appendix suppuration.

Table 6 shows a comparison of preoperative factors between perforated and unperforated patients during appendectomy. The gender and age between two groups were not significantly different ($P = 0.199$, $P = 0.949$ respectively). The proportion of the first onset, time interval from symptom onset to operation, the preoperative US revealed periappendiceal fluid between two groups were significantly different ($P < 0.001$, $P = 0.020$, $P = 0.001$ respectively). The preoperative leukocyte count and neutrophil percentage between the perforated group and unperforated group were significantly different (mean: 14.8 vs. $10.8 \times 10^9/L$, $P = 0.001$ and 83.6 vs. 73.1%, $P < 0.001$). Multivariable logistic regression analysis showed that only high neutrophil percentage (OR 1.074, 95% CI 1.004, 1.150, $P = 0.038$) were independently associated appendix perforation.

**Discussion**

Acute appendicitis (AA) is the most common surgical emergency, but establishing the diagnosis of acute appendicitis based on clinical presentation and physical examination is still challenging. Several clinical scoring systems have been developed for early diagnosis of AA. The most popular for use in adult and children was the Alvarado score [15]. Two other systems such as the AIR score and the AAS score were also used currently, and they could
decrease negative appendectomy rates in low-risk groups and reduce the need for imaging studies and hospital admissions in both low and intermediate risk groups [16–19]. All the cases in this study were definitively diagnosed with appendicitis before they were admitted to the hospital. We use the Alvarado score assess appendicitis in Table 5 and Table 6.

**Table 5** Risk factors for appendix suppuration identified by univariate and multivariate logistic regression analysis

|                    | Non-suppurative | Suppurative | Z/χ² value | P value | OR (95%CI) | P value |
|--------------------|-----------------|-------------|------------|---------|------------|---------|
| Gender             |                 |             |            |         |            |         |
| Male               | 35              | 54          | 1.938      | 0.164   | 0.878 (0.363, 2.119) | 0.772   |
| Female             | 48              | 49          |            |         | Reference  |         |
| Age, years         | 37.5 (16 ~ 73)  | 42.4 (14 ~ 81) | - 2.055   | 0.040*  | 1.025 (0.995, 1.056) | 0.099   |
| First onset        |                 |             |            |         |            |         |
| No                 | 48              | 20          | 29.242     | <0.001* | 0.591 (0.223, 1.567) | 0.290   |
| Yes                | 35              | 83          |            |         | Reference  |         |
| Time interval from on-set to operation, days | | | | | | |
| ≤ 1                | 21              | 43          | 29.967     | <0.001* | 1.820 (0.355, 9.326) | 0.472   |
| 1 < and ≤ 2        | 18              | 40          |            |         | 2.614 (0.525, 13.012) | 0.241   |
| 2 < and ≤ 3        | 9               | 13          |            |         | 1.339 (0.200, 8.971) | 0.764   |
| > 3                | 30              | 6           |            |         | Reference  |         |
| Preoperative leukocyte count, × 10⁹/L | 84.2 (2.1 ~ 18.3) | 13.8 (2.7 ~ 24.3) | - 6.734 | <0.001* | 1.109 (0.975, 1.262) | 0.116   |
| Preoperative neutrophil percentage, % | 64.7 (30.5 ~ 92.8) | 82.5 (45.6 ~ 95.8) | - 8.129 | <0.001* | 1.109 (1.051, 1.169) | <0.001* |
| Preoperative US revealed periappendiceal fluid | No | 78 | 69 | - | <0.001* | 0.138 (0.034, 0.561) | 0.006* |
| Yes                | 4               | 31          |            |         | Reference  |         |

**Table 6** Risk factors for appendix perforation identified by univariate and multivariate logistic regression analysis

|                    | Unperforated | perforated | Z/χ² value | P value | OR (95%CI) | P value |
|--------------------|--------------|------------|------------|---------|------------|---------|
| Gender             |              |            |            |         |            |         |
| Male               | 73           | 16         | 1.648      | 0.199   | 1.224 (0.447, 3.355) | 0.694   |
| Female             | 86           | 11         |            |         | Reference  |         |
| Age, years         | 40.1 (14 ~ 81) | 41.0 (17 ~ 78) | - 0.064   | 0.949   | 0.995 (0.966, 1.025) | 0.752   |
| First onset        |              |            |            |         |            |         |
| No                 | 67           | 1          | -          | <       | 0.166 (0.020, 1.419) | 0.101   |
| Yes                | 92           | 26         |            | 0.001*  | Reference  |         |
| Time interval from on-set to operation, days | | | | | | |
| ≤ 1                | 58           | 6          | 9.443      | 0.020*  | 0.210 (0.032, 1.379) | 0.104   |
| 1 < and ≤ 2        | 48           | 10         |            |         | 0.475 (0.081, 2.789) | 0.410   |
| 2 < and ≤ 3        | 14           | 8          |            |         | 1.584 (0.236, 10.637) | 0.636   |
| > 3                | 33           | 3          |            |         | Reference  |         |
| Preoperative leukocyte count, × 10⁹/L | 10.8 (2.1 ~ 24.3) | 14.8 (2.7 ~ 22.8) | - 3.448 | 0.001* | 1.074 (0.960, 1.201) | 0.214   |
| Preoperative neutrophil percentage, % | 73.1 (30.5 ~ 95.8) | 83.6 (60.3 ~ 94.1) | - 3.612 | <0.001* | 1.074 (1.004, 1.150) | 0.038* |
| Preoperative US revealed periappendiceal fluid | No | 132 | 15 | 10.400 | 0.001* | 0.594 (0.202, 1.749) | 0.344   |
| Yes                | 24           | 11         |            |         | Reference  |         |

**OR odds ratio, CI confidence interval, US ultrasonography**

*P value is statistically significant
patients with abdominal pain in the emergency department. When the score was greater than 4, to further clarify the diagnosis, the patient was advised to have an US examination of appendix or plain CT scan of the lower abdomen with negative US findings. Patients established appendiceal abscess were treated with antibiotics and percutaneous drainage of abscess if needed. Others established simple or complex appendicitis were advised of surgical removal of the appendix.

Although urgent appendicectomy is still the recommended treatment for acute uncomplicated appendicitis, antibiotics have been proposed as a single treatment for uncomplicated appendicitis with controversy [4, 20, 21]. A meta-analysis of appendectomy vs. antibiotic treatment showed that although antibiotic treatment alone can be successful, a failure rate at 1 year was around 25–30% with need for readmission or surgery [22]. It was suggested that an antibiotics-first strategy may be considered in those who have strong preferences for avoiding an operation or who have contraindications to surgery [23]. In the Shandong Provincial Hospital affiliated to Shandong First Medical University between January 2018 and December 2019, there were 186 patients (86.1%) treated with urgent appendicectomies eligible, and there were 30 patients (13.9%) treated with antibiotics and other managements. In the operating patients of this study, the first onset of appendicitis accounted for 63.4% and recurrent appendicitis for 36.6%. Whether to have appendectomy were consistent with the patients’ decisions according to the doctor’s advice, and there was no negative appendicectomy. All the appendectomies were successful and no death was reported, with a laparoscopic appendectomy rate of 83.3% and open appendectomy rate of 16.7%. Our study supports that urgent appendicectomy using LA or OA in patients which were definitely diagnosed by relevant symptoms, signs, laboratory and imaging results were safe and effective.

In this study, the majority of patients with acute appendicitis can be successfully managed with laparoscopy, however, the operation time ranged from 20 to 190 min, 14 (9.0%) of LA converted to OA, 4 patients (2.2%) performed extended ileocecal resection instead of appendicectomy, postoperative complications occurred in 10 patients (5.4%). Previous studies showed that the most common reasons for conversion from laparoscopic to open appendectomy are severe inflammatory adhesions, a pre-operative diagnosis of complicated appendicitis (perforated or gangrenous appendicitis), presence of peri-appendiceal abscess and diffuse peritonitis, because of obscuring the anatomy or resulting in friability or perforation [10, 11, 13]. And we found that the main reason of conversion-to-open and extended resection was adhesions as recorded in the operation notes. Peritoneal adhesions or intra-abdominal adhesions mean the state of close connection caused by the fibrous tissue between abdominal organs and peritoneum. They are often caused by inflammation, injury, ischemia and other reasons, and make operations difficult. All 14 patients of conversion-to-open had intraoperative severe degree of adhesions, laparoscopic appendectomy could be hardly completed in such cases because appendix and other organs around were badly attached and it was easy to damage the intestine or other organs without the hand touch feedback. We also found that severe adhesions were contributed to longer operation time, longer post-operative hospital stay, higher intraoperative suppuration rate, higher intraoperative perforation rate, and more postoperative complications. Therefore, it is necessary to find out risk factors of severe periappendiceal adhesions and give appropriate treatment.

The experienced veteran surgeons of our hospital believed that appendicitis lasting more than 3 days was not appropriate for surgical treatment because of severe abdominal adhesions. Most of these patients were supported with antibiotics and percutaneous drainage of abscess if needed. However, outcomes in relation to timing of surgery have been controversial. Some studies show that a longer length of preoperative stay significantly increased the risk of complications and mortality, also caused extensive resection for acute appendicitis [24–27]. And other studies show that short delays of less than 24 h before appendicectomy were not associated with increased rates of complex pathology in selected patients, but symptomatic time > 48 h were independently associated with complications [28, 29]. To make clear whether a longer length of preoperative stay was contributed to more adhesions, we divided the time interval from symptom onset to operation into four groups: ≤ 1 day, > 1 day and ≤ 2 days, > 2 days and ≤ 3 days, > 3 days, and took whether the first onset of appendicitis into account. The difference of intraoperative adhesions in each group was compared. Univariate analysis and multivariate logistic regression analysis showed no difference between each group of the time interval from symptom onset to operation. The risk factors influencing periappendiceal adhesions were recurrent appendicitis and high neutrophil percentage before operation. This suggests that chronic inflammation is a possible cause of periappendiceal adhesions, and those recurrent appendicitis with high neutrophil percentage had higher risk of adhesions. Furthermore, to investigate whether the time interval from initial symptom onset to operation was related to adhesions in recurrent appendicitis, we divided it into three groups: ≤ 3 months, > 3 months and ≤ 12 months, > 12 months. Univariate analysis showed no difference between each group of different
time interval. Multivariate logistic regression analysis showed no preoperative factors of adhesions in recurrent appendicitis were significant.

It was recommended that POCUS (point-of-care US) was the most appropriate first-line diagnostic tool in both adults and children, if an imaging investigation was indicated based on clinical assessment [17]. Overall sensitivity and specificity of US is 76% and 95% and for CT is 99% and 84% respectively [30], and appendicitis could be effectively diagnosed with them. However, the usefulness of CT for determining perforation or adhesions in AA is limited [31]. In our hospital, We use US more than CT for diagnosing appendicitis because of no radiation, cheaper and more convenient. And we tried to find more evidence that US predicted appendiceal suppuration, perforation or adhesions. As the results showed, preoperative US with periappendiceal fluid was a risk factor of appendix suppuration, but not of appendix perforation and adhesions. Multivariate logistic regression analysis showed that an increased percentage of neutrophils was the only risk factor of appendix perforation, and it was also a risk factor of appendix suppuration.

In this study, we found that recurrent appendicitis and increased preoperative neutrophil percentage are risk factors for intraoperative periappendiceal adhesions, and adhesions can lead to prolonged operation time and hospital stay, more often accompanied by suppuration and perforation, resulting in more postoperative complications. Therefore, for those patients with severe adhesions, immediate appendectomy should be given first, and the appendix can be removed at an elective time 3 months later when periappendiceal adhesions was reduced, so as to reduce the surgical risks caused by adhesions. Nevertheless, the present study has some limitations. It is a retrospective analysis and a single-center study; therefore, it has some inherent biases. The judgement of the appendiceal degree of adhesions may be objective and was based on the operative surgeons. The US examinations were not performed by a single person. The preoperative risk factors studied were not comprehensive, CT and CRP were not routinely examined and included in the study.

Conclusions
In cases of appendicitis, we demonstrated that recurrent appendicitis and preoperative high neutrophil percentage were risk factors of periappendiceal adhesions; preoperative US revealed periappendiceal fluid and high neutrophil percentage were risk factors of appendix suppuration; and a high preoperative neutrophil percentage was a risk factor of appendix perforation. In this study, no effect of operation timing on appendiceal adhesions, suppuration and perforation was found.

Acknowledgements
Not applicable.

Author contributions
YM contributed to the study conception and design. SG and XG contributed to the study, by patient recruitment and follow-up data collection. Material preparation, data collection, and analysis were performed by LL and CJ. The first draft of the manuscript was written by YM. All authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

Funding
This work was supported in part by the Grant 81672379 from the National Natural Science Foundation of China.

Availability of data and materials
The data used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was approved by the Human-involved Biomedical Research Ethics Committee of Shandong Provincial Hospital, Jinan, Shandong (SWYX NO. 2022027) and complied with the tenets of the Declaration of Helsinki. The consent to participate from the patients was waived by the Human-involved Biomedical Research Ethics Committee of Shandong Provincial Hospital due to the retrospective and non-interventional nature of the study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
1Department of Gastroenterological Surgery, Shandong Provincial Hospital, Cheeloo College of Medicine, Shandong University, Jinan 250021, Shandong, China. 2Department of Gastroenterological Surgery, Shandong Provincial Hospital Affiliated to Shandong First Medical University, Jinan 250021, Shandong, China.

Received: 5 October 2021 Accepted: 23 March 2022
Published online: 08 April 2022

References
1. Ferris M, Quan S, Kaplan BS, Molodecky N, Ball CG, Chernoff GW, et al. The global incidence of appendicitis: a systematic review of population-based studies. Ann Surg. 2017;266:237–41. https://doi.org/10.1097/SLA.0000000000002188.
2. Styrdal I, Eriksson S, Nilsson J, Ahlberg G, Haapaniemi S, Neovius G, et al. Appendectomy versus antibiotic treatment in acute appendicitis. A prospective multicenter randomized controlled trial. World J Surg. 2006;30:1033–7. https://doi.org/10.1007/s00268-005-0304-6.
3. Ozguc H, Ilgiz C, Kaya E, Tokay R. Randomized controlled trial of appendectomy versus antibiotic therapy for acute appendicitis. Br J Surg. 1995;82:1284. https://doi.org/10.1002/bjs.1800820949.
4. Hansson J, Körner U, Khorsam-Manesh A, Solberg A, Lundholm K. Randomized clinical trial of antibiotic therapy versus appendicectomy as primary treatment of acute appendicitis in unselected patients. Br J Surg. 2009;96:473–81. https://doi.org/10.1002/bjs.6482.
5. Coccolini F, Fugazzola P, Sartelli M, Cicuttin E, Sibilla MG, Leandro G, et al. Conservative treatment of acute appendicitis. Acta Bio-medica Alenri Parmensis. 2018;89:119–34. https://doi.org/10.23750/abm.v89i2.5.7905.
6. Jaschinski T, Mosch CG, Eikermann M, Neugebauer EA, Sauerland S. Laparoscopic versus open surgery for suspected appendicitis. Cochrane Database Syst Rev. 2018;11:CD001546. https://doi.org/10.1002/14651858.CD001546.pub4.

7. Biondi A, Di Stefano C, Ferrara F, Bellia A, Vacante M, Piazza L. Laparoscopic versus open appendectomy: a retrospective cohort study assessing outcomes and cost-effectiveness. World J Emerg Surg. 2016;11:44. https://doi.org/10.1186/s13017-016-0102-5.

8. Ulka T, Shikata S, Takeda H, Dawes L, Noguchi Y, Nakayama T, et al. Evidence of surgical outcomes fluctuates over time: results from a cumulative meta-analysis of laparoscopic versus open appendectomy for acute appendicitis. BMC Gastroenterol. 2016;16:37. https://doi.org/10.1186/s12876-016-0453-0.

9. Li X, Zhang J, Sang L, Zhang W, Chu Z, Li X, et al. Laparoscopic versus conventional appendectomy—a meta-analysis of randomized controlled trials. BMC Gastroenterol. 2010;10:129. https://doi.org/10.1186/1471-230X-10-129.

10. Finnerty BM, Wu X, Giamborone GP, Gaper-Baylis LK, Zabih R, Bhat A, et al. Conversion-to-open in laparoscopic appendectomy: a cohort analysis of risk factors and outcomes. Int J Surg (London, England). 2017;40:169–75. https://doi.org/10.1016/j.ijsu.2017.03.016.

11. Antonacci N, Ricci C, Taffurrelli G, Monari F, Del Governatore M, Caira A, et al. Laparoscopic appendectomy: which factors are predictors of conversion? A high-volume prospective cohort study. Int J Surg (London, England). 2015;21:103–7. https://doi.org/10.1016/j.ijsu.2015.06.089.

12. Wagner PL, Eeachempati SR, Aronova A, Lydo LJ, Pieracci FM, Bartholdi M, et al. Contemporary predictors of conversion from laparoscopic to open appendectomy. Surg Infect. 2011;12:261–6. https://doi.org/10.1089/sir.2010.079.

13. Sakpal SV, Bindra SS, Chamberlain RS. Laparoscopic appendectomy conversion rates two decades later: an analysis of surgeon and patient-specific factors resulting in open conversion. J Surg Res. 2012;176:42–9. https://doi.org/10.1016/j.bjsr.2011.07.019.

14. Chen Y, Pei W, Wang Q, Wang W, Xu T, Jing C, et al. One-stitch versus traditional method of protective loop ileostomy in laparoscopic low anterior rectal resection: a retrospective comparative study. Int J Surg (London, England). 2020;80:117–23. https://doi.org/10.1016/j.ijsu.2020.06.035.

15. Alvarado A. A practical score for the early diagnosis of acute appendicitis. Ann Emerg Med. 1986;15:557–64. https://doi.org/10.1016/S0196-0644(86)80093-3.

16. Sammal Korpi HE, Mentula P, Leppäniemi A. A new adult appendicitis score improves diagnostic accuracy of acute appendicitis—a prospective study. BMC Gastroenterol. 2014;14:114. https://doi.org/10.1186/1471-230X-14-114.

17. Di Saveno S, Podda M, De Simone B, Ceresoli M, Augustin G, Gori A, et al. Diagnosis and treatment of acute appendicitis: 2020 update of the WSES Jerusalem guidelines. World J Emerg Surg. 2020;15:27. https://doi.org/10.1186/s13017-020-00306-3.

18. Andersson M, Kolodziej J, Andersson RE, Group SS. Randomized clinical trial of Appendicitis Inflammatory Response score-based management of patients with suspected appendicitis. Br J Surg. 2017;104:1451–61. https://doi.org/10.1002/bjs.10637.

19. Andersson M, Andersson RE. The appendicitis inflammatory response score: a tool for the diagnosis of acute appendicitis that outperforms the Alvarado score. World J Surg. 2008;32:1843–9. https://doi.org/10.1007/s00268-008-9649-y.

20. Vons C, Barry C, Maitre S, Pautrat K, Lecente M, Costaglioli B, et al. Amoxicillin plus clavulanic acid versus appendectomy for treatment of uncomplicated appendicitis: an open-label, non-inferiority, randomised controlled trial. The Lancet. 2011;377:1573–9. https://doi.org/10.1016/S0140-6736(11)60410-8.

21. Wilms IM, Suykerbyk-de Hoog DE, de Visser DC, Janzing HM. Appendectomy versus antibiotic treatment for acute appendicitis. Cochrane Database Syst Rev. 2020;10:CD008359. https://doi.org/10.1002/14651858.CD008359.pub3.

22. Martínez Carrillo J. Safety of the “antibiotics first” strategy. N Engl J Med. 2015;372:1937–43. https://doi.org/10.1056/NEJMcp1215006.

23. Flum DR. Clinical practice. Acute appendicitis—appendectomy or the “antibiotics first” strategy. N Engl J Med. 2015;372:1937–43. https://doi.org/10.1056/NEJMcp1215006.

24. Canal C, Lemper M, Biner D, Neuhaus V, Turina M. Short-term outcome after appendectomy is related to preoperative delay but not to the time of day of the procedure: a nationwide retrospective cohort study of 9224 patients. Int J Surg (London, England). 2020;76:16–24. https://doi.org/10.1016/j.ijssu.2020.02.001.

25. Saida F, Matsumoto S, Kitano M. Preoperative predictor of extensive resection for acute appendicitis. Am J Surg. 2018;215:599–602. https://doi.org/10.1016/j.amjsurg.2017.06.033.

26. Busch M, Gutzwiller F, Aellig S, Kuettel R, Metzger U, Zingg U. In-hospital delay increases the risk of perforation in adults with appendicitis. World J Surg. 2011;35:1626–33. https://doi.org/10.1007/s00268-011-1101-z.

27. Teixeira PG, Sivrikoz E, Inaba K, Talving P, Lam M, Demetriades D. Appendectomy timing: waiting until the next morning increases the risk of surgical site infections. Ann Surg. 2012;256:538–43. https://doi.org/10.1097/SLA.0b013e318265e1a3.

28. Kim JW, Shin DW, Kim DJ, Kim JY, Park SG, Park JH. Effects of timing of appendectomy on the risks of perforation and postoperative complications of acute appendicitis. World J Surg. 2018;42:1295–303. https://doi.org/10.1007/s00268-017-4280-4.

29. Bhangar A. Safety of short, in-hospital delays before surgery for acute appendicitis: multicentre cohort study, systematic review, and meta-analysis. Ann Surg. 2014;259:894–903. https://doi.org/10.1097/SLA.0000000000000492.

30. Chang ST, Jeffrey RB, Olcott EW. Three-step sequential positioning algorithm during sonographic evaluation for appendicitis increases appendiceal visualization rate and reduces CT use. AJR Am J Roentgenol. 2014;203:1006–12. https://doi.org/10.2214/AJR.13.12334.

31. Gaskill CE, Simianu V, Carmell J, Hippe DS, Bhangar A, Flum DR, et al. Use of computed tomography to determine perforation in patients with acute appendicitis. Curr Probl Diagn Radiol. 2018;47:6–9. https://doi.org/10.1067/j.cpradiol.2016.12.002.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.