Chapter

Adhesive Small Bowel Obstruction in the Minimally Invasive Era

Pepijn Krielen, Martijn W. J. Stommel, Richard P. G. ten Broek and Harry van Goor

Abstract

Roughly 60% of all cases of small bowel obstruction are caused by adhesions. Adhesions are a form of internal scar tissue, which develop in over 45–93% of patients who undergo abdominal surgery. With this relatively high incidence, the population at risk for adhesive small bowel obstruction (ASBO) is enormous. Minimally invasive surgery reduces surgical wound surface and thus holds promise to reduce adhesion formation. The use of minimally invasive techniques results in a 50% reduction of adhesion formation as compared to open surgery. However, since ASBO can be caused by just a single adhesive band, it is uncertain whether a reduction in adhesion formation will also lead to a proportional decrease in the incidence of ASBO. Minimally invasive surgery might also improve operative treatment of ASBO, accelerating gastro-intestinal recovery time and lowering the risk of recurrent ASBO associated with adhesion reformation. We will discuss recent evidence on the impact of minimally invasive surgery on the incidence of ASBO and the role of minimally invasive surgery to resolve ASBO. Finally, we will debate additional measures, such as the use of adhesion barriers, to prevent adhesion formation and adhesion-related morbidity in the minimally invasive era.

Keywords: adhesions, adhesive small bowel obstruction, minimally invasive surgery, laparoscopy, adhesion barrier, adhesion reduction strategies

1. Introduction

As many as 60% of all episodes of small bowel obstruction (SBO) are caused by adhesions [1]. Adhesions are attachments of abdominal structures by internal scar tissue that are the result of healing of the peritoneum after it has been damaged, in most cases by surgery [2]. Adhesions can be filmy or dense and be present as an isolated band or as a 'curtain' or tangle with difficulty recognizing visceral structures. The degree of density and vascularization is traditionally classified using the Zühlke classification (**Table 1**) [3]. A more comprehensive and clinically relevant classification including projected locations of adhesions is the Peritoneal Adhesion Index (PAI) (**Figure 1**) [4, 5].

Adhesions develop in 89–93% of patients undergoing open abdominal or pelvic surgery [6, 7]. Incidence rates of adhesion formation are lower after minimally invasive surgery, 45–62% [7, 8]. Adhesions can also develop after other causes of peritoneal trauma, such as inflammatory conditions or radiotherapy [2].

Grade	Description
0	No adhesions or insignificant adhesions
I	Adhesions that are filmy and easy to separate by blunt dissection
II	Adhesions with beginning vascularization that can be dissected blunt but some sharp dissection is necessary
III	Adhesions with clear vascularization that can only be dissected using sharp dissection
IV	Adhesions which strongly attached organs, dissection is only possible by sharp dissection, damage of organs is hardly preventable

Adapted from Ref. [3].

Table 1.
Zühlke classification.

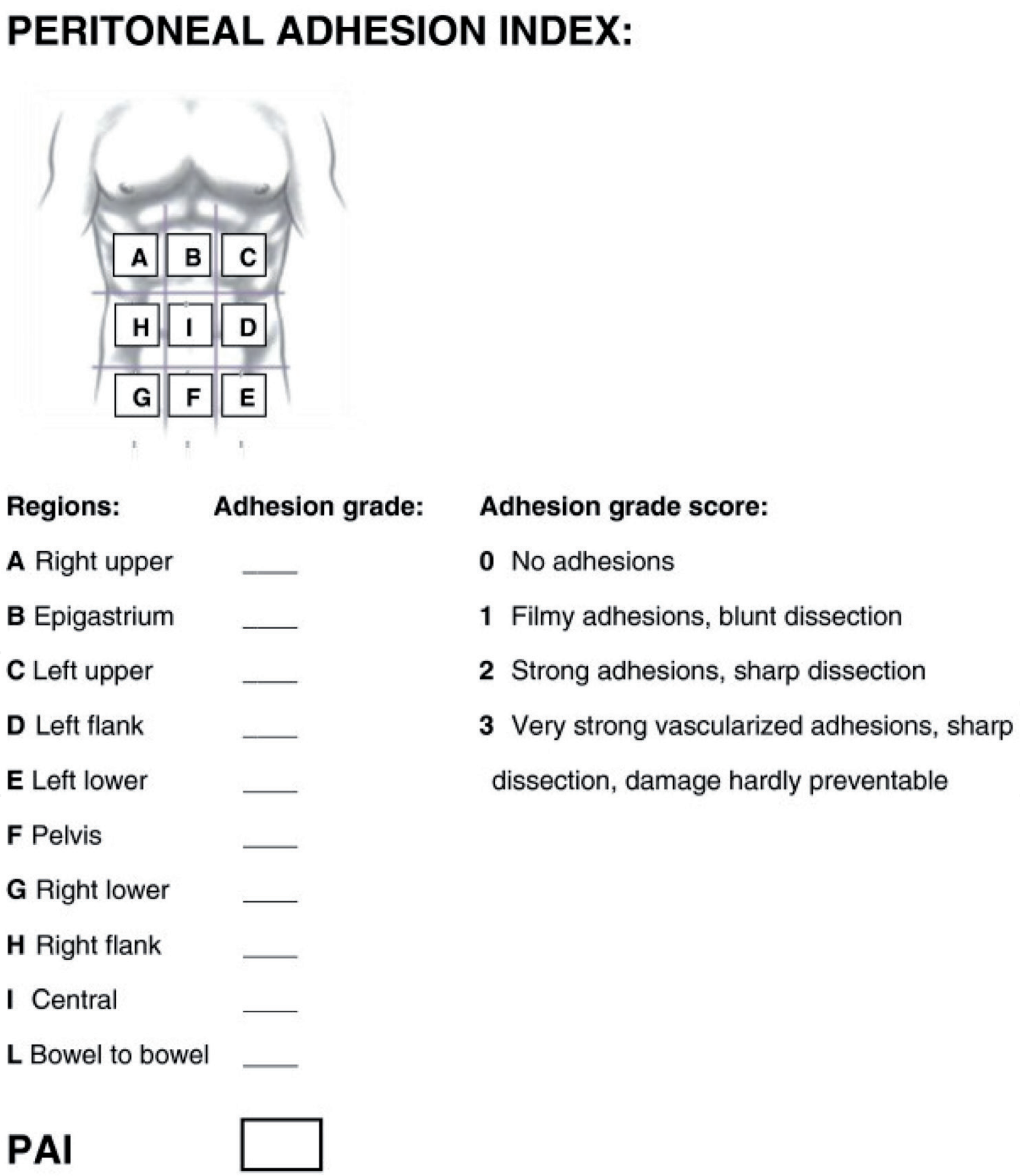

Figure 1.
Peritoneal adhesion index.

The occurrence of adhesions does not only cause a lifelong risk of adhesive small bowel obstruction (ASBO). Other clinical consequences of adhesions are difficulties during reoperation, female infertility, and chronic visceral pain; making it the most common cause of long-term complications in peritoneal surgery [1]. The incidence of ASBO is 2–3% in the first years after surgery in all patients who undergo abdominal or pelvic surgery [1]. The risk of ASBO depends on the anatomical location of surgery and the extent of surgery and peritoneal injury [1–10]. ASBO risk varies from 0.5% in abdominal wall surgery, 1.2% after upper gastrointestinal tract surgery to 3.2% in lower gastro-intestinal tract surgery and 4.2% in pediatric surgery [1].

Given the high incidence of adhesions and adhesion-related complications, one would assume that every surgeon is aware of the risks of adhesions. However, awareness on the full size of the problem only arose in response to the publication of the Surgical and Clinical Adhesion Research (SCAR) study two decades ago. The SCAR large population based study demonstrated that one of three patients undergoing abdominal surgery is readmitted for a cause possibly related to adhesions [11]. Subsequently adhesion-related complications gained increasing awareness of clinicians, hospitals and vendors, and adhesion reduction strategies were introduced. Laparoscopic surgeons hypothesized that minimally invasive surgical techniques would reduce peritoneal injury and thereby could solve the problem of adhesion formation. Other strategies to reduce adhesion formation were the development of adhesion barriers, the banishment of powdered gloves, and the introduction of new sealing devices [12].

Over the past decades, minimally invasive surgery has become the standard approach in many surgical disciplines. The rapid introduction of minimally invasive surgery was largely fueled by short-term benefits such as quicker recovery, reduced pain, and better cosmetic outcome [13]. Furthermore, surgeons strongly believed in the effectiveness of minimally invasive surgical techniques to reduce adhesion formation and subsequent morbidity [14]. For this reasons adhesion barriers are only seldomly used in minimally invasive surgery [15], and are believed to be needed only in open surgery. Despite good evidence of effective reduction of adhesion formation and subsequent adhesion-related morbidity, the use of adhesion barriers in open surgery is also limited [16]. Reasons for not using adhesion barriers are the lack of trust in adhesion reduction, the expected limited impact on adhesion-related complications, and the costs of the barriers [15]. The limited use of adhesion barriers has slowed down the research and development of adhesion-prevention strategies in the past decade.

Studies on adhesion formation in minimally invasive surgery report a reduction of approximately 50% in the extent of postoperative adhesions compared with open surgery [7]. Unfortunately, trials comparing open and minimally invasive surgery have not been designed and powered to compare long-term adhesion-related outcomes [17]. Therefore, the effect of the broad implementation of minimally invasive surgery on clinically relevant outcome parameters such as ASBO and readmissions is unknown [17]. A reduction in adhesion formation, does not necessarily correlate with a proportionate reduction in the risk of ASBO; a single adhesive band may cause a life-threatening bowel obstruction, whereas extensive dense abdominal adhesions may be asymptomatic [18]. Nevertheless, potential benefits of minimally invasive surgery in preventing adhesion-related morbidity seem compelling.

Minimally invasive surgery may also play a role in the treatment of ASBO. Approximately 25% of patients with ASBO require surgery to resolve the bowel obstruction [1], and recurrence rates are high [19]. The minimally invasive approach is hypothesized to accelerate recovery, and might also reduce risk of regrowth of adhesions and subsequent recurrence of ASBO. A caveat is the small working space and vulnerability of the bowel caused by the distention of the obstructed bowel that could result in iatrogenic injuries. In this chapter, we discuss recent evidence on the effects of the introduction of minimally invasive surgery on the burden of adhesions and ASBO. We further discuss the role of minimally invasive surgery in the treatment of patients with ASBO. We end with a contemplation on the awareness of adhesion-related complications and the value of adhesion barriers in minimally invasive surgery.

2. The problem of adhesive small bowel obstruction

The vast majority of adhesions develop after abdominal or pelvic surgery, although adhesions can also form after abdominal and pelvic radiation and peritoneal inflammation [2]. Adhesions are associated with a lifelong risk of ASBO. Incidence and morbidity of ASBO might be somewhat difficult to estimate and compare between studies based on different definitions for ASBO. Most accepted definition of ASBO is an episode of SBO with the presence of adhesions confirmed during reoperation. However, operative confirmation of adhesions is often not possible because many ASBO episodes are managed non-operatively. Therefore a second definition of ASBO is commonly applied: an episode of SBO interpreted as matching ASBO on radiological imaging after excluding other potential causes of bowel obstruction e.g. hernia, tumor, bezoar.

In a systematic review, the incidence of SBO by any cause after surgery is estimated 9% [1]. In 42 etiological studies on SBO, adhesions accounted for 56% of all SBO episodes, either by operative confirmation or by excluding all other potential causes of SBO [1]. The incidence of postoperative ASBO confirmed by surgery is estimated at 2.4%. Depending on the type of initial surgical procedure, the incidence varied between 0.5 and 4.2% [1]. As mentioned, this estimate is conservative because most episodes of ASBO are managed non-operative.

Another way to estimate the burden of ASBO is based on population studies. In the SCAR study more than one in three patients were readmitted for a cause possibly related to adhesions, and more than 1 in 20 patients (6%) who underwent open abdominal or pelvic surgery were readmitted for a directly adhesion-related cause [11]. The most common diagnosis for a directly adhesion-related readmission was ASBO [11]. More recent population studies in the UK and USA show that ASBO remains a major contributor to the morbidity, mortality and costs related to emergency abdominal surgery. In the UK in 2016, 51% of all emergency laparotomies were for ASBO [20]. Similar results were found in the USA between 2008 and 2011, where SBO needing adhesiolysis belonged to the top 5 of emergency surgical procedures [21]. Given these numbers and the number of patients undergoing abdominal or pelvic surgery, the impact of ASBO on a population level is high.

ASBO causes significant morbidity and a hospital admission for SBO is associated with 2.5% mortality [1]. Initial non-operative management of ASBO includes gastric decompression, fluid resuscitation and nil per os, which is successful in 70–90% [1–23]. In a sizable number of cases ASBO will result in emergency or delayed, after failed initial conservative management, abdominal surgery. Open or minimally invasive adhesiolysis to resolve the obstruction is associated with a incidence of 6–20% enterotomies [24, 25]. In general, complex adhesiolysis is associated with bleeding, sepsis, wound infections and increased mortality, even in the absence of bowel injury [26]. Mean length of hospital stay for ASBO ranges from 4 to 13 days and generally depends the type of treatment and the treatment complications [1].

Both operative and conservative management of ASBO are associated with a risk of recurrent ASBO. Operative management includes repeated peritoneal injury with risk of adhesion reformation and re-ASBO. Non-operative management of ASBO does not dissolve abdominal adhesions and harbors the risk of a new episode of ASBO. In a recent study of patients presenting with a first episode of ASBO, operative management was associated with a lower risk of recurrence compared with non-operative management (13% vs. 21%) after a median follow-up of 3.6 years [19]. The study also showed an increased risk of ASBO with every previous episode of ASBO in accordance to findings done 25 years ago [27]. Also the time between episodes of ASBO decreases with an increase in number of episodes [19]. Despite the higher recurrence rate after conservative treatment, current guidelines still recommend a trial of non-operative management of ASBO in order to avoid the risk of complications associated with surgical intervention [28].

Effort is made to predict the severity of ASBO using peri-operative scores [29, 30]. However, the scores are not widely adopted for clinical use. The American Association for the Surgery of Trauma (AAST) developed a score based on clinical, imaging, operative and pathologic criteria to grade disease severity of ASBO [31, 32]. The AAST grade uses clinical criteria (flatus, bowel sounds abdominal distention), pathologic criteria (bowel perforation), imaging criteria on CT (intestinal distention, transition point, contrast flow) and operative criteria (intestinal distention, impeding bowel compromise, peritonitis) to define the grade of ASBO on a scale from 1 to 4. A higher AAST score for emergency ASBO is associated with an increase in length of hospital stay, pneumonia, and more severe complications [33]. Recently the Clinical Adhesion Score (CLAS) was developed, measuring the full spectrum of the long-term burden of adhesion formation in post-operative patients. CLAS calculates the overall morbidity based on four domains: ASBO, difficulties during reoperation, female infertility or subfertility, and chronic abdominal pain (data not yet published). Evaluation of current and new adhesion prevention strategies regarding long-term clinical efficacy e.g. ASBO could benefit from using CLAS.

The economic burden of ASBO is high. Operative management is the single most important determinant of costs. However, based on fewer recurrences of ASBO after surgical treatment, surgery may save costs at the long term [34]. Several studies have been reported regarding the treatment costs of ASBO. Most have important limitations reporting part of the costs or costs based on reimbursement prices rather than true healthcare costs [35–37]. We modeled in a recent study, costs for ASBO in the Netherlands using a micro-costing method including costs of length of stay, ICU days, operative time, medication, parenteral feeding, imaging studies and laboratory studies [38]. This modeling revealed total healthcare costs of patients operated for ASBO of €16305 (SD €2513) with a mean hospital stay of 16.0 ± 11 days. For non-operatively treated patients costs would be €2277 (SD €265) with a mean hospital stay of 4.0 ± 2.0 days. The majority of the costs were due to ward stay, operative time, ICU stay and (parental) feeding. All surgical procedures for ASBO in this study consisted of open adhesiolysis. Costs estimated in this study were higher compared to previous estimates of treatment costs for ASBO with comparable lengths of stay and, as a result of its design better reflecting reality [35–37]. In the study we adhered to international guidelines for the diagnosis and treatment of ASBO increasing generalizability of outcomes for developed countries.

Nevertheless costs may vary among countries due to differences in admission and discharge policies, and prices of diagnostics, materials, medication and feeding.

3. Impact of minimally invasive surgery on morbidity of ASBO

It has been suggested from a few studies that the decreased adhesion formation after minimally invasive surgery associates with a lower incidence of ASBO. This decrease seems limited compared to open surgery as concluded from one systematic review and one trial reported by our group [1–17]. Differences in definitions of ASBO used, types of procedures, outcome parameters and length of follow-up in the studies, preclude a firm conclusion on the beneficial effect of minimally invasive surgery on development of ASBO.

To estimate the impact of minimally invasive surgery at a population level on adhesion-related complications, ASBO in particular, our group recently reported the results of the SCAR update study [39]. Over 72,000 patients, who were operated between June 2009 and June 2011, were followed for a minimum of 5 years. Readmissions were classified, according to the initial SCAR study (1999), as directly-related to adhesions e.g. adhesive small bowel obstruction, possibly related to adhesions, e.g. any small bowel obstruction and reoperations potentially complicated by adhesions e.g. right hemicolectomy years after an appendectomy. Approximately 30% of all index procedures were minimally invasive. Patients who underwent minimally invasive surgery were readmitted less frequently for directly related causes compared with patients after open surgery (1.7% vs. 4.3%). Possibly related readmissions and reoperations potentially complicated by adhesions were also less frequent (16.0% vs. 18.2% and 8.6% vs. 15.0%). Multivariate analysis revealed a 32% reduction in directly adhesion-related readmissions associated with minimally invasive surgery. Readmission rates were similar when comparing patients with open surgery in the SCAR and those in the SCAR update study. The overall small differences found in readmission rates could be explained by the difference in follow-up, 10 years in the SCAR study and 5 years in the SCAR update study. Despite the finding of a small reduction in readmission rates after initial minimally invasive surgery, the overall burden of adhesion-related readmissions on a population level remains high.

To further elaborate differences in adhesion-related readmissions between minimally invasive and open surgery, we analyzed patients with colorectal procedures (data not yet published). This type of surgery is known for its adhesion formation propensity and associated morbidity. Over 15,000 patients underwent colorectal surgery of whom almost one-third with a minimally invasive approach. For open colorectal surgery readmission rates were comparable between the SCAR study and the SCAR update study. Minimally invasive colonic and/or rectal surgery reduced the total number of directly adhesion-related readmissions. However in patients who underwent a (sub)total colectomy readmission rates were over 15% irrespective of an open or minimally invasive approach. Minimally invasive surgery did not reduce adhesion-related complications in rectal procedures. We concluded that an extended colectomy and rectal resection do not benefit from minimally invasive surgery regarding adhesion-related complications. We hypothesized that the large extent of the dissection and injury to the visceral and lateral parietal peritoneum needed in both surgical techniques abolishes the preventive effect of the minimally invasive technique on adhesion formation to the ventral peritoneum, where the injury is relatively limited for both approaches.

The SCAR update study has demonstrated that minimally invasive surgery is associated with less adhesion-related readmissions. Hence, the overall burden of adhesion-related readmissions on a population level remains high. Adhesion formation therefore continues to be a challenge in abdominal surgery, also in the minimally invasive era. Minimally invasive procedures were only performed in approximately one-third of procedures in 2009–2011, whereas currently in the Netherlands about 75% of colonic resections are performed minimally invasive (by laparoscopy or robot) [40]. On a population base a further decline in adhesion-related complications can be expected with an increase of minimally invasive abdominal operations. However, we like to warn against unbridled optimism regarding the overall impact of minimally invasive surgery on the burden of adhesions because open surgery is still being preferred when a complicated condition is expected in the abdominal cavity e.g. after multiple previous procedures, with large inflammatory mass or locally advanced cancer [41]. Many of these conditions are complex specifically due to presence of adhesions at baseline surgery and the need to perform adhesiolysis before entering the operative area. It is known that the propensity to reform adhesions after adhesiolysis is higher than de novo adhesion formation.

4. Management of adhesive small bowel obstruction

Adequate management of ASBO depends on an initially correct diagnosis. Although ASBO is a common diagnosis with clear signs and symptoms, misdiagnosis and delayed diagnosis are a substantial clinical problem. Up to 50% of older patients are initially not adequately diagnosed [42]. Failure to diagnose represents 70% of malpractice claims in ASBO [43, 44]. In this regard it is important to note that patients with ASBO can initially present themselves to a variety of physicians, including general practitioners, surgeons, internal medicine physicians, geriatricians and gastroenterologists. To improve diagnosis of ASBO, multiple specialists need to be involved in practice guidelines and protocols.

Based on expert opinion the diagnosing of ASBO includes a medical history with an assessment of potential causes of SBO, e.g. previous abdominal surgery, inflammatory bowel disease, important symptoms such as vomiting, absence of stools or flatus, intermittent colicky abdominal pain and abdominal distention. Common pitfalls in diagnosing ASBO are the less prominent pain present in the elderly [42], reporting of watery diarrhea by patients with an incomplete obstruction and normal stool passage in the first days after onset due to stool still present in the colon.

The recent update of the international guidelines for diagnosis and management of ASBO gives the current best available evidence for management of ASBO once the diagnosis of bowel obstruction has been established [28]. The first priority in management is to establish the cause of obstruction and to determine if urgent surgical treatment is required. ASBO is the single most common cause for SBO, the differential diagnosis includes strangulated abdominal wall or groin hernia, tumor, paralysis, constipation or bezoars. Laboratory tests should include blood count, CRP, electrolytes, creatinine and lactate. Imaging studies can include water-soluble contrast studies or computer tomography (CT) scans. CT scan is the preferred imaging technique for the diagnosis of ASBO, it can accurately rule out other causes of obstruction and identify patients who might require emergency surgery [28]. Water-soluble contrast enhances the diagnostic accuracy of CT scans. Signs that might suspect ASBO on imaging studies are an abrupt change in bowel diameter and the exclusion of other causes of SBO. The value of plain X-rays is limited [28].

Urgent surgery is required in case of signs of ischemia, perforation or strangulation of the bowel, generalized peritonitis and/or hemodynamic instability. No single test is highly sensitive for ischemia and strangulation. Sensitivity of physical examination for the detection of strangulation is only 48% in experienced hands [45]. Laboratory tests indicating peritonitis or ischemia are a CRP above 75 and a white blood cell count above 10.000/mm^3 [45–47]. Again, a CT scan is most accurate in assessing strangulation and perforation and the need for emergency surgery [28]. CT abnormalities indicating strangulation or perforation are free intraperitoneal air or fluid, closed loop obstruction, mesenteric edema or engorgement, mesenteric swirling, pneumatosis intestinalis, decreased or lack of bowel enhancement or thickened bowel wall [48–50].

If bowel obstruction is caused by adhesions, and signs of peritonitis, ischemia, and strangulation are absent, initial conservative treatment is reportedly safe. Conservative treatment is successful in 70–90% of all episodes of ASBO [1–23]. Conservative treatment of ASBO consists of nil per os and decompression of the gastro-intestinal tract using a naso-gastric tube. Further management includes fluid resuscitation, correction of electrolyte disturbances, nutritional support and prevention of aspiration. Optimal duration of a conservative trial is debated; prolonged management for more than 72 h has been associated with adverse outcomes and increased mortality [20, 51–54]. Water-soluble contrast studies seem useful in the follow-up of conservative management of ASBO. If contrast has not reached to colon 24–48 h following administration, continuation of conservative management is likely to fail and surgical management should be considered [28].

An algorithm for the diagnosis and treatment of ASBO is presented in **Figure 2** [28].

4.1 Role of minimally invasive surgery in the management of ASBO

Operative treatment of ASBO historically comprises an explorative laparotomy with adhesiolysis. The increased use of minimally invasive surgery has raised the question whether minimally invasive surgery is feasible and effective for the treatment of ASBO. Benefits of minimally invasive adhesiolysis are reduction of peritoneal injury possibly resulting in less adhesion reformation, a quick recovery and minimal post-operative pain. Twenty-five years ago the first cases of minimally invasive surgery for treatment of ASBO have been described [55]. Thereafter a few series were reported but adequate comparative trials are scarce [56–60]. Minimally invasive surgery for ASBO is challenging because there is little laparoscopic working space due to the distended bowel. Also visibility can be hampered by multiple adhesions. There are concerns that minimally invasive surgery increases the risk of iatrogenic bowel perforations [57]. Suitability of minimally invasive surgery for ASBO further depends on patient characteristics. In case of hemodynamic instability open surgery is required because patients cannot tolerate the pneumoperitoneum.

One randomized trial comparing minimally invasive and open surgery for ASBO has been performed [56]. Only patients with a high suspicion of a single adhesive band causing the obstruction were included. Patients with confirmed or suspected peritoneal carcinosis, known multiple adhesions, previous open surgery for endometriosis, aorta, iliac vessels or Crohn's disease, previous generalized peritonitis, abdominal malignancy, previous abdominal radiotherapy or recent operations within 30 days were all excluded. Patients started with conservative management of ASBO. If the obstruction did not resolve patients were randomized between open and laparoscopic adhesiolysis. The trial was open label, therefore patients and care providers were not blinded. During 5 years 566 patients were included in the study, 104 patients underwent surgery, 51 were randomly assigned to the open surgery

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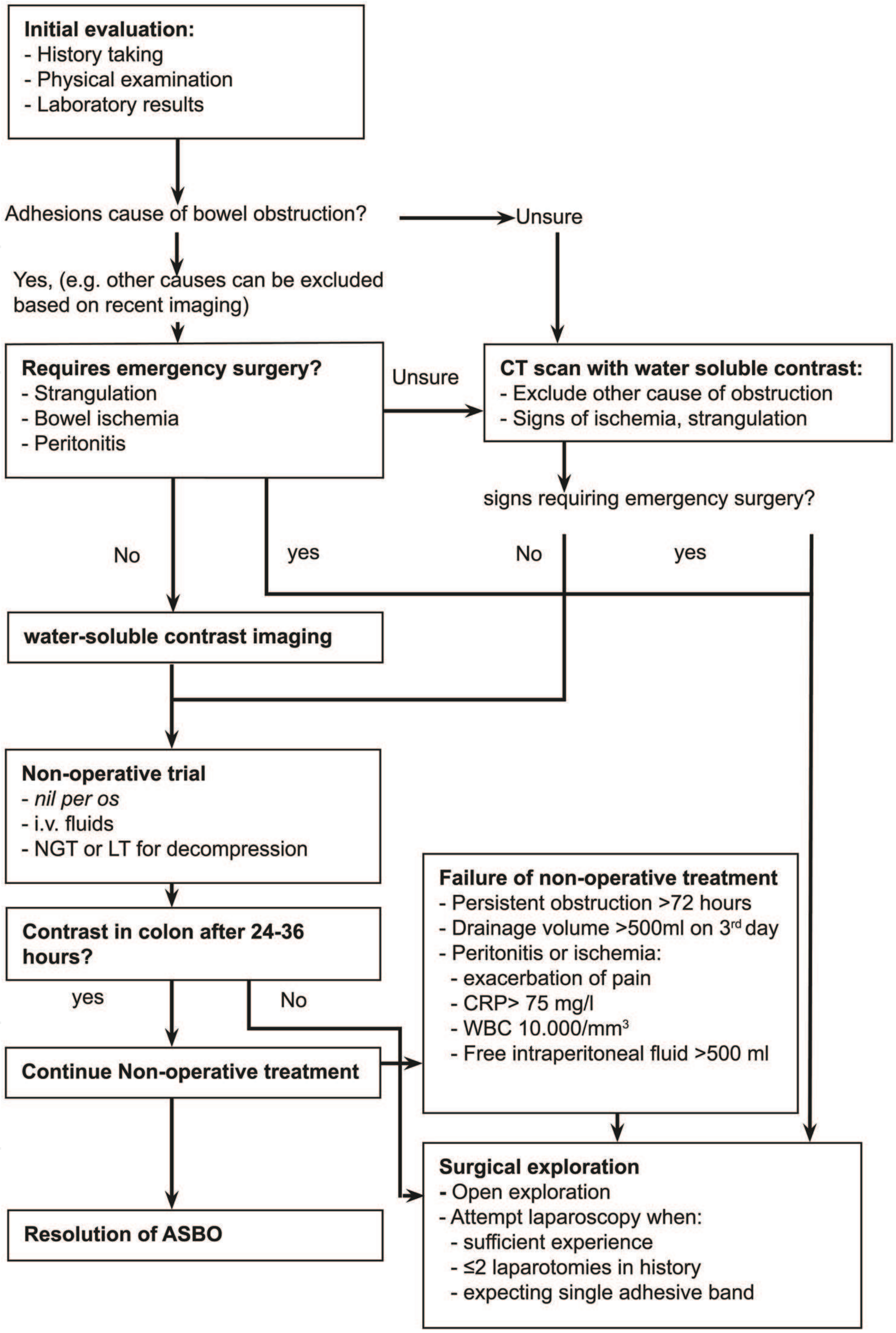

Figure 2.
Algorithm for the diagnosis and treatment of ASBO.

group, and 53 to the laparoscopic surgery group. Patients in the laparoscopic group had a shorter length of stay (4.2 days) compared with the open group (5.5 days). Mortality and postoperative complications did not differ between the groups.

The few matched cohort studies comparing minimally invasive and open surgery for ASBO reported comparable results to those of the trial mentioned above

[59, 60]. There seems a trend towards a faster recovery in selected patients. Studies showed no major differences in complications or mortality. A few studies specifically addressed the potential drawbacks of the minimally invasive approach and suggested an increased risk of bowel injury [59]. Notably, the non-matched cohorts frequently claim large beneficial effects of the laparoscopic approach [40–58]. However, these studies have a high risk of various types of selection bias, mainly excluding patients who are more sick or are suspected of multiple adhesions.

It seems that minimally invasive adhesiolysis holds promise for patients with signs of a single adhesive band and an uncomplicated disease course. Further studies are needed to identify patients who can benefit from minimally invasive adhesiolysis and patients who can be harmed by minimally invasive treatment for ASBO.

5. Future perspectives

5.1 Awareness of adhesions formation by minimally invasive surgery

Morbidity of adhesion formation in minimally invasive surgery is often underestimated. Less than 25% of surgeons and 5–83% of gynecologists routinely inform their patients about adhesions and the life term risk of adhesion-related complications [14–62]. However, recent evidence shows that adhesion-related morbidity remains high in the minimally invasive era [39]. Not informing patients about the risk of adhesions might therefore be considered negligent. Increased awareness of adhesions might create an urge for the development and refinement of adhesion prevention strategies.

Awareness of adhesions may improve by growing awareness for intra-operative complications in general. Impact of adhesions on the operative course of reoperations for ASBO or other indications is often underreported. In a prospective comparison of operative notes and observation by an independent researcher, one in seven iatrogenic bowel injuries was not reported in operative notes, and almost one in three minor injuries [63]. In recent years, there is increasing scientific interest in the consequences of intra-operative events. IAEs are associated with 40% more hospital admissions, a twofold higher readmission rate, and with worse post-operative outcome [64–70]. Recently the Classification of Intraoperative Complications (CLASSIC) has been developed as a new tool for systematic classification for intra-operative complications (iAEs) [71]. CLASSIC defines iAEs as any deviation from the ideal intraoperative course, including technical failures, surgical and anesthesiological difficulties. The score has been update to five grades of severity (https://clinicaltrials.gov/ct2/show/NCT03009929). Lysis of adhesions at reoperations is associated with post-operative increase of sepsis, intra-abdominal complications, wound infections, longer hospital stay, and higher hospital costs [26–72]. As such, adhesiolysis qualifies as an iAE if adhesiolysis is not the intended surgical procedure. We currently investigate the contribution of adhesiolysis and associated intra-operative complications e.g. bleeding, inadvertent enterotomy to the CLASSIC.

Recent published guidelines may also increase awareness of adhesions and treatment of ASBO [28]. An old saying on ASBO is 'you must not let the sun rise on ASBO', all patients presenting with ASBO were operated if conservative management failed to resolve the bowel obstruction within 24 h. Recent insights report that a conservative trial can safely be prolonged to 72 h [51, 52]. The current guideline states that conservative treatment should be instigated in all patients without signs of ischemia, perforation or strangulation of the bowel, generalized peritonitis and/or hemodynamic instability [28]. Contradictory, some studies report lower recurrence rates of ASBO after surgical management of ASBO [19–27]. A further disadvantage of prolonged conservative management is the further clinical deterioration of highly comorbid patients who receive starvation treatment for a few days [73]. Minimally invasive surgery could change the paradigm again towards earlier surgical intervention because of faster recovery, reduced length of hospital stay and the mentioned lower recurrence rates of ASBO.

5.2 Adhesion reduction strategies

Considering the high impact of adhesion-related complications on a population level that is not substantially decreased by minimally invasive surgery, there is a pressing need to develop new adhesion reduction strategies.

Until now the most promising approach for reduction of adhesion formation is routinely applying an adhesion barrier. Adhesion barriers are bioresorbable liquids, gels or films that keep injured peritoneal wound surfaces separated. During separation the peritoneal wound can heal with restoration of peritoneal tissue morphology and function without 'scarring' (adhesions). A large systematic review and meta-analysis in 2014 of 28 trials (n = 5191) showed benefits of several adhesion barriers in predominantly open abdominal surgery [16]. However, adhesion barriers are seldomly applied in abdominal or pelvic surgery [14]. Only 1 in 7 surgeons ever uses adhesion barriers [14]. Reluctance of surgeons to use adhesions barriers seems caused by doubts about cost-effectiveness and the need and possibility of adhesion prevention in minimally invasive surgery.

Cost-effectiveness of adhesion prevention in minimally invasive surgery is an important perquisite for implementation in every day practice. We performed a modeling study on cost-effectiveness of adhesion barriers in minimally invasive procedures with a high risk of adhesion formation [74]. Two strategies were compared: current clinical practice (colorectal surgery without the use of an adhesion barrier) and colorectal surgery with the use of an adhesion barrier (hyaluronate carboxymethylcellulose). Whilst hyaluronate carboxymethylcellulose as such is not applicable in minimally invasive surgery and a gel form has not properly been studied in minimally invasive surgery, probabilities were extrapolated from data of open colorectal surgery. Probability estimates were derived from literature. Costs of treatment of ASBO were derived from our previous report [38]. Cost of hyaluronate carboxymethylcellulose was estimated on $630, based on the mean number of films used in studies on hyaluronate carboxymethylcellulose [12–75]. We concluded that using an adhesion barrier was more effective than not using a barrier in minimally invasive surgery, but it was more expensive. However, mean expected direct healthcare costs in the 4 years following index surgery increased with only $163 per patient. Cost estimates in this modeling study only included direct health care costs. Societal costs (e.g. absence from work) were not modeled in this study. Therefore an increase of $163 in direct health care may be neglectable considering potential gain in societal costs. Further research is needed on long term savings regarding socio-economic costs with adhesion barriers also including the new SCAR update data of minimally invasive surgery.

An important limitation of most barriers is the inability to properly use these in minimally invasive surgery. Most barriers were developed more than two to three decades ago and were films intended for use in open surgery. This limitation and the disregard needing barriers in minimally invasive surgery have impeded implementation and continued research and development of barriers suitable for minimally invasive surgery (and open surgery). Recently some new barriers have been developed suitable for minimally invasive surgery. Studies on these new barriers are performed mostly in gynecologic populations, and show effectiveness reducing adhesions [76, 77]. The important next step in adhesion prevention is the development of a new generation of barriers suitable for minimally invasive use in general surgery [78, 79]. Using increased knowledge of the pathophysiology of adhesions, new barriers consist of bioactive and targeted technology e.g. modulation of inflammation [2]. Pilpel and colleagues developed a liquid solution modulating the fibrin matrix which is generated by the hemostatic system after peritoneal injury [80]. This novel therapy is currently tested in animal models. Roberston and colleagues are testing a drug (L-Alanyl-L-Glutamine) to regulate the formation of adhesions due to hypoxia and oxidative stress caused by surgical injury of the vascular supply to the tissue caused by surgical intervention [81]. The first results of this drug in a double-blinded placebo controlled study show that L-Alanyl-L-Glutamine is safe to use and is effective at reducing adhesion formation after laparoscopic myomectomies [82]. Definitive results from this study are expected in due time. When proven safe, effective and affordable in patients, these new bioactive and targeted technology agents should be administered during index minimally invasive surgery to break the sequence of intra- and postoperative adhesion-(re) formation related complications.

6. Conclusions

Adhesion-related morbidity remains a clinically relevant problem in the minimally invasive era. Minimally invasive surgery is associated with only a modest reduction in adhesion-related readmissions and incidence of ASBO. The growing body of scientific evidence provides the clinician with a firm guideline for the diagnosis and treatment of ASBO. Minimally invasive surgery in the management of ASBO appears to be safe and effective alternative to open adhesiolysis, however in a very selected patient group. To allow as many patients as possible to benefit from a minimally invasive approach future research should focus on the selection criteria for minimally invasive surgery in ASBO. Adhesion-related morbidity is often underestimated and complications of adhesiolysis underreported. Raising awareness of adhesions therefore remains important. Using newly proposed scores for intraoperative complications, may increase awareness for the intra-operative events caused by adhesions. Adhesion barriers can safely reduce adhesion formation, are cost-effective in open colorectal surgery and effective with slightly higher costs in minimally invasive surgery. Future research should focus on new bioactive barriers that are easily applicable in minimally invasive abdominal surgery and safe to use. Preventing adhesions during first minimally invasive surgery is key to break the sequence of intra- and postoperative adhesion (re)formation related complications.

Conflict of interest

The authors declare no conflict of interest.

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