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REVIEW ARTICLE

The role of non-invasive imaging techniques in detecting intra-abdominal adhesions: a systematic review

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Abstract

Background Intra-abdominal adhesions after surgery are highly prevalent. Adhesions implicate complications during subsequent surgery and can cause chronic abdominal pain. The objective of this review was to investigate the usefulness of non-invasive diagnostic methods for detection of adhesions.

Methods We searched the electronic databases: MEDLINE, Embase, and The Cochrane Central Register of Controlled Trials for studies investigating the use of non-invasive diagnostic imaging techniques for detecting adhesions. Main outcome was the sensitivity and specificity of each technique. We used the Quality Assessment of Diagnostic Accuracy studies tool to assess bias.

Results In total, 25 studies were included: 18 using ultrasound (US), 5 using magnetic resonance imaging (MRI), 1 using computed tomography (CT), and 1 using both US and MRI. A total of 2195 patients were included. Overall accuracy ranged between 76 and 100% for US studies and between 79 and 90% for MRI and was 66% for CT. Sensitivity ranged between 21 and 100% for US and between 22 and 93% for MRI and was 61% for CT. Specificity was 32–100% for US, 25–93% for MRI, and 63% for CT. Bias analysis revealed that in most studies, investigators were blinded to the reference standard but not to the index test and 11 of 25 studies had a high risk of selection bias.

Conclusions Currently, abdominal US can be used to determine the presence of adhesions between bowel and the abdominal wall. MRI is also an accurate diagnostic modality and can in addition visualize adhesions between viscera, however, with a tendency to over diagnose adhesions. There is insufficient evidence to support CT as a diagnostic modality for adhesions.

Keywords Abdomen · Adhesions · Ultrasound · Magnetic resonance imaging · Computed tomography · Visceral slide

Study acronym: NITA

Registered at PROSPERO (2016:CRD42016037139)

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Introduction

After intra-abdominal surgery, there is a risk of developing intra-abdominal peritoneal adhesions [1, 2]. The most common complication to postoperative adhesion formation is the increased lifetime risk of developing small bowel obstruction, as well as more prolonged and chronic challenges such as female infertility, difficulties at subsequent surgery, and chronic abdominal pain [3–5]. Currently, the only option to positively confirm suspected adhesions in patients is through exploratory surgery [6, 7]. For this, diagnostic laparoscopy is preferable to open surgery, as it is much less likely to generate new adhesions [8–10]. However, laparoscopic entry to the abdomen is associated with higher risk of iatrogenic bowel injuries if adhesions are present. One study investigating laparoscopy-related bowel injury found that in the event of bowel injury, adhesions/previous laparotomy was implicated in 68.9% of cases and was associated with conversion to open surgery in 78.6% [11]. Although iatrogenic bowel injury is a rare occurrence, it carries a high risk of morbidity and mortality [12, 13].

With the ongoing development and improvement of non-invasive diagnostic imaging like ultrasound (US), magnetic resonance imaging (MRI), and computed tomography (CT), it is relevant to examine if these modalities can identify the presence of abdominal adhesions, both as a diagnostic tool prior to laparoscopic procedures and in patients with chronic abdominal pain, which could be caused by adhesions.

The objective of this review is to identify and systematically review the existing literature on non-invasive imaging methods for the detection of intra-abdominal adhesions.

Methods

This review was done in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement [14]. The study protocol was registered at the International Prospective Register of Systematic Reviews (PROSPERO) before undertaking the review (identification no.: 2016:CRD42016037139) [15].

Eligibility criteria

The included population consisted of patients of age 15 or above. We included all studies performing non-invasive diagnostic imaging to ascertain the presence of intra-abdominal adhesions in a patient group, and the results had to be compared to our gold standard, which was defined as the recording of adhesions during surgery. The included studies had to have the following outcomes: data assessing the accuracy of the diagnostic test (i.e., specificity, sensitivity) or data comparing different diagnostic imaging modalities. We excluded studies involving animal testing and patients with known disposing diseases (peritoneal carcinomatosis, benign or malignant abdominal tumors, endometriosis and tuberculosis). There were no restrictions in regard to study design and no limitations on date of publication. Only studies retrievable in full text and in English were included.

Information sources and search strategy

A search was performed using the electronic databases: MEDLINE/PubMed, Excerpta Medica (EMBASE), and The Cochrane Central Register of Controlled Trials (CENTRAL). Additionally, a manual search of the references of included studies and identified reviews was conducted.

A search string was developed with the assistance of a research scholar from the Copenhagen University Library for MEDLINE and modified to the other databases. Search terms included free text and MeSH terms.

The search string used for MEDLINE is included in Appendix in the supplementary material.

Study selection

All potentially relevant records were screened by title and/or abstract by two authors (AD, JG), and potentially relevant records were read in full text. The inclusion and exclusion of studies required agreement between two authors (AD, JG). If agreement could not be reached by discussion, a third author made the decision (FB). Relevant data was extracted by the primary author (JG).

Data extraction

A predefined form in a customized Microsoft Excel spread sheet (2011 for Mac, Version 14.0.0, ©Microsoft Corporation) was used for data extraction. The data extracted were as follows: study design, year of publication, population characteristics (no. of patients, age, gender, body mass index, previous abdominal surgery), diagnostic image modality used, blinding, gold standard used, and accuracy of tests (overall accuracy, sensitivity, specificity, positive predictive value, negative predictive value).

Risk of bias assessment

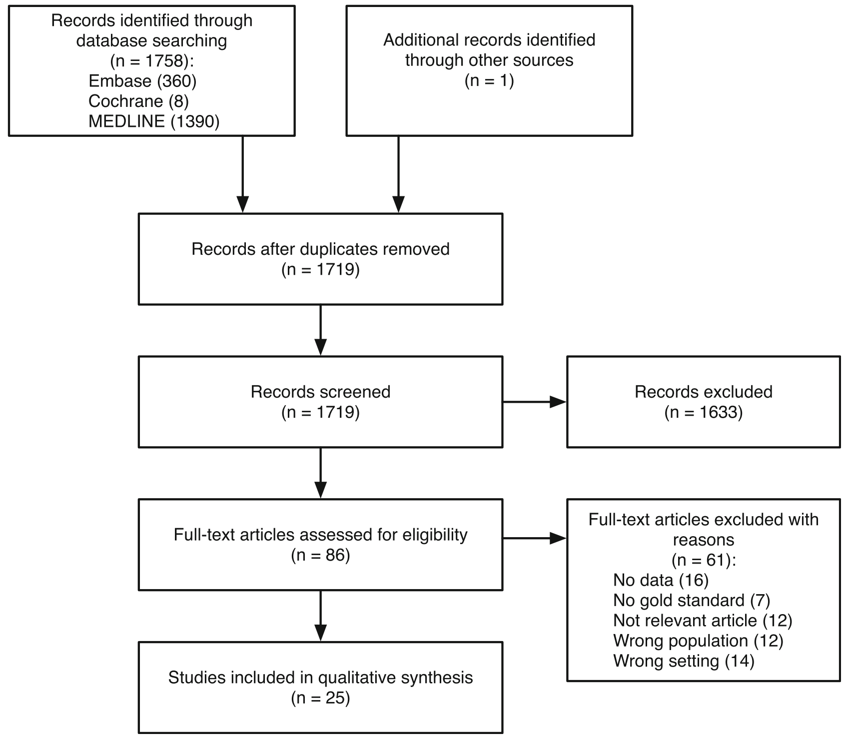
The included studies were evaluated on study level for bias and quality, using the revised tool for quality assessment of diagnostic test accuracy studies (QUADAS-2) [16] in accordance with the recommendations of the Cochrane Collaboration [17]. QUADAS-2 is a tool that assesses the quality of diagnostic accuracy studies, based on four key domains: patient selection, index test, reference standard, and flow and timing. Each domain is addressed separately through several signaling questions. If the answer to one signaling question indicates a risk of bias, the whole domain is flagged as being at high risk of bias, although, in agreement with the recommendations in manual of QUADAS-2, few exceptions to this procedure have been made, when a certain signaling question had been deemed of little importance to this review as specified in the bias assessment protocol, which can be found in Appendix in the supplementary material.

Results

Study selection and study characteristics

Database search and review of the reference lists of included studies yielded 1719 studies and 1 review [18], of which 25 studies were included in a final synthesis (Fig. 1). The included articles consisted of 18 studies evaluating the presence of

Fig. 1 Study selection process



adhesions through ultrasound (US) [19–36], 5 studies on magnetic resonance imaging (MRI) [37–41], 1 study on computed tomography (CT) [42], and 1 study evaluating both US and MRI [43]. All studies evaluated prospective cohorts scheduled for surgery except for one, which analyzed a retrospective cohort [42]. The total patient population of the included studies was $n = 2195$. Population characteristics can be found in Table 1.

All US studies used the visceral slide technique, which depends on the natural excursion of internal organs to the abdominal wall when the diaphragm displaces them during a respiratory cycle. Adhesions are suspected when such an excursion is impeded. Some studies used spontaneous respiration to induce the visceral slide as originally described by Sigel et al. [19, 21, 33] whereas most US studies used exaggerated deep inspiration [20, 22–32, 34–36, 43]. Some studies tried to investigate other ultrasonic signs as indicators of adhesion including the disruption of the peritoneal-parietal reflection band [22] and a reduction in distance between the urachus and peritoneum in the subumbilical field [28]. MRI studies used cine-MRI, running several imaging cycles while instructing the patients to use Valsalva's maneuver to increase their intra-abdominal pressure and thus provoke movement of abdominal contents in relation to each other. The lack of visceral slide and separation between organs as well as between organs and the abdominal wall was interpreted as a sign of adhesion [37–41, 43]. Two studies also ran a cycle where the patients were instructed to breathe deeply [41, 43]. One CT study described the linear impression band on small bowel in patients with small bowel obstruction (SBO), as a sign of an adhesive band [42].

Table 1 General characteristics of the population in the included studies

Patient population (no.)	2195
Gender characteristics[1]	
Male (no.)	368
Female (no.)	1477
Age[2] (years)	16–97
Previous surgery[3] (no.)	1568
% of total population	77

[1] Seven studies were missing information on gender

[2] Five studies were missing information on age

[3] Two studies were missing information on previous surgery

Risk of bias

An overview of the bias analysis (QUADAS-2) can be seen in Table 2.

When it came to concerns for risk of bias in patient selection domain, nine studies were at high risk of bias as they included patients that had very low risk of adhesions since they had never undergone surgery [20, 21, 24–26, 28, 30, 33, 43], and in one study, the risk was unclear due to insufficient information [36]. One study's patient selection also gave a high risk of bias as it made inappropriate patient exclusions [27]. Applicability concerns in the same domain were present in seven studies due to their inclusion of patients with hernias,

Table 2 Diagnostic accuracy and bias analysis of the included studies

			Results					Risk of bias				Applicability concerns		
	Study	*n*	Accuracy (%)	Sensitivity (%)	Specificity (%)	PPV[1] (%)	NPV[2] (%)	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Computed tomography	Petrovic et al. [42]	103	66	63	70	77	55	Low	Low	High	Low	Yes	No	No
Magnetic resonance imaging	Buhmann-Kirchhoff et al. [37]	90	89	31–75	65–92			Low	Low	High	Low	No	No	No
	Kirchhoff et al. [38]	25	84					Low	High	High	Low	Yes	No	No
	Lang et al. [39]	89	90	93	25	96	14	Low	Low	High	Low	No	No	No
	Langbach et al. [40]	18	72	70	75	78	67	Low	Low	Low	Low	Yes	No	No
	Lienemann et al. [41]	13		88	93			Low	Low	High	Low	No	No	No
	Zinther et al. [43]	60	72	22	87	83	79	High	Low	Low	Low	Yes	No	No
Ultrasound	Arnaud et al. [19]	51	78	83	74	76	81	Low	Low	Low	Low	Yes	No	No
	Aube et al. [20]	76	76	79	75	67	85	High	Low	Low	Low	Yes	No	No
	Balique et al. [21]	72	76	79	75	67	85	High	Low	Low	Low	Yes	No	No
	Borzellino et al. [22]	130	89	100	32	88	100	Low	Low	High	Low	No	No	No
	Caprini et al. [23]	30		100				Low	Low	High	Low	Yes	No	No
	Hsu et al. [24]	512	100	100	100	100	100	High	Low	High	Low	No	No	No
	Kodama et al. [25]	18	83	57	100	100	79	High	Low	High	Low	No	No	No
	Kolecki et al. [26]	110	91	90	92	90	92	High	Low	High	Low	No	No	No
	Kothari et al. [27]	50	97	78	98	54	99	High	Low	High	Low	No	No	No
	Larciprete et al. [28]	47	100	100	100	100	100	High	Low	High	Low	No	No	No
	Minaker et al. [29]	145	76	99	70	47	99	Low	Low	High	Low	No	No	No
	Nezhat et al. [30]	150	96	50	98	50	98	High	High	High	Low	No	No	No
	Nezhat et al. [31]	70	99	83	100	100	99	Low	Low	High	Low	No	No	No
	Piccolboni et al. [32]	60	93	87	96	87	96	Low	Low	High	Low	No	No	No
	Sigel et al. [33]	18	89	67	100	100	86	High	Low	High	Low	No	No	No
	Steitz et al. [34]	124	97	96	100	100	90	Low	Low	High	Low	No	No	No
	Tu et al. [35]	60	90	86	91	55	98	Low	High	High	Low	No	No	No
	Uberoi et al. [36]	48	76	21	94			Unclear	Low	Low	Low	No	No	No
	Zinther et al. [43]	60	81	24	98	76	82	High	Low	Low	Low	Yes	No	No

[1] Positive predictive value

[2] Negative predictive value

which might interfere with the visceral slide technique [19–21, 23, 38, 40, 43]. The only study examining CT was also flagged for concerns for applicability, since it included only patients with SBO and thus the images reviewed by the investigators all showed dilated bowels on which the specific sign was demonstrated.

The analysis of the domains concerning the index test (US, MRI, or CT) and the reference standard (surgery) revealed that two studies did not provide any information on whether they had blinded the assessor doing the index test to the results of the reference standard nor was the surgeon blinded to the results of the index test [30, 38]. The majority of the studies did the index test without knowledge of the results of the reference standard, but the surgeon assessing the presence of adhesions was aware of the results of the index test [22–29, 31–35, 37, 39, 41, 42]. Only five studies were double-blinded [19–21, 40, 43]. Studies without proper blinding were regarded as being at high risk of bias in their relevant domains. One US study was considered being at high risk of bias with regard to the index test, because it did not have a specified threshold for the visceral slide [35]. There were no concerns with regard to applicability in the domains concerning the index test or the reference standard.

In the domain regarding the flow and timing of the included studies, analysis showed no increased risk of bias as all studies received the same reference standard; all included patients were in the final analysis, and there was an appropriate time between the index tests and surgery.

Results of the individual studies

Results of each study are shown in Table 2.

Studies assessing the ability of US to detect adhesions to the abdominal wall showed an overall accuracy of 76 to 100%. Sensitivity varied between 21 and 100%. Specificity was found to be between 32 and 100%. Studies providing sufficient data to construct confidence intervals are depicted in Fig. 2. It is noted that studies with sensitivity below 90% have wide confidence intervals [25, 30–32, 35], which is also the case for one study that found a sensitivity of 100% [24], due to low prevalence of adhesions. In general, specificity was found to be high with narrow confidence intervals, except for one study that found a high prevalence of adhesions [22].

The studies examining the use of MRI in the diagnosis of intra-abdominal adhesions showed accuracy between 72 and 90%. In four MRI studies, they found a sensitivity of 22 to 93% and specificity of 25 to 93% [39–41, 43]. One study reported sensitivity and specificity for nine different zones on the abdomen [37]. Each zone was defined according to a nine-zoned grid, superimposed on the abdomen. Sensitivity varied between 31 and 75% and specificity between 65 and 92%. The zones in the lower abdomen showed the lowest specificity. Two studies contained adequate data to construct confidence intervals and are illustrated in Fig. 2 [39, 40].

The only study examining CT showed an accuracy of the linear impression sign in patients with SBO of 66%. Sensitivity was found to be 63% and specificity 70%, with confidence intervals that are depicted in Fig. 2 [42].

Discussion

In this systematic review, we found that US is most accurate in the diagnosis of adhesions between viscera and the abdominal wall through the use of the visceral slide technique. Although there was a large variance in study results when it came to sensitivity and specificity, five of six US studies with a patient population of more than 100 found a sensitivity of 90 to 100%

Ultrasound studies

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Borzellino (1998)	108	0	15	7	0.88 [0.81, 0.93]	1.00 [0.59, 1.00]
Hsu (2006)	2	0	0	510	1.00 [0.16, 1.00]	1.00 [0.99, 1.00]
Kodama (1992)	4	0	3	11	0.57 [0.18, 0.90]	1.00 [0.72, 1.00]
Kolecki (1994)	43	5	5	57	0.90 [0.77, 0.97]	0.92 [0.82, 0.97]
Larciprete (2009)	17	0	0	30	1.00 [0.80, 1.00]	1.00 [0.88, 1.00]
Nezhat (2009)	2	2	3	143	0.40 [0.05, 0.85]	0.99 [0.95, 1.00]
Nezhat (2014)	5	0	1	64	0.83 [0.36, 1.00]	1.00 [0.94, 1.00]
Piccolboni (2009)	13	2	2	43	0.87 [0.60, 0.98]	0.96 [0.85, 0.99]
Sigel (1991)	4	0	2	12	0.67 [0.22, 0.96]	1.00 [0.74, 1.00]
Steitz (1997)	85	0	4	35	0.96 [0.89, 0.99]	1.00 [0.90, 1.00]
Tu (2005)	6	5	1	48	0.86 [0.42, 1.00]	0.91 [0.79, 0.97]

MRI studies

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Lang (2008)	79	3	6	1	0.93 [0.85, 0.97]	0.25 [0.01, 0.81]
Langbach (2016)	7	2	3	6	0.70 [0.35, 0.93]	0.75 [0.35, 0.97]

CT studies

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Petrovic (2006)	40	12	23	28	0.63 [0.50, 0.75]	0.70 [0.53, 0.83]

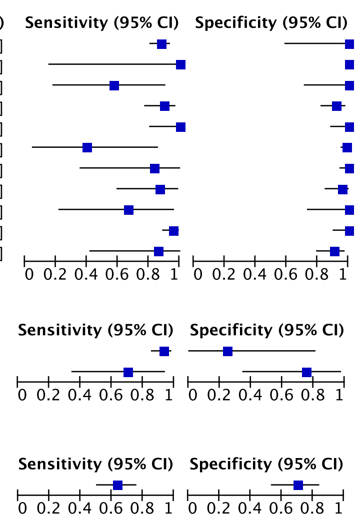


Fig. 2 Sensitivity and specificity analysis in studies with sufficient data to construct confidence intervals (CI). TP true positive, FP false positive, FN false negative, TN true negative

[22, 24, 26, 29, 34], although in one, it was at the expense of a low specificity [22]. Specificity was in general higher than sensitivity with 13 of 19 studies reaching specificity greater than 90% [24–28, 30–36, 43]. The MRI studies did not find an accuracy, sensitivity, or specificity as high as the US studies, but most studies showed comparable results and variation. In addition, MRI also found adhesions between organs as well as adhesions to the abdominal wall. At the moment, there is insufficient evidence to support the use of CT in the diagnosis of adhesions.

For these imaging techniques to be of clinical relevance, it is important that they can identify the presence of adhesions in specific anatomic locations. The MRI studies first divided the abdomen into nine anatomically defined zones and then ascertained the presence of adhesions in those zones for correlation with intra-operative findings [37–41, 43]. Ultrasound studies using visceral slide only determined whether there were adhesions between viscera and bowel, although further anatomical considerations were also made in majority of studies (16 of 19 studies). Eight studies had predefined zones for adhesion assessment [20, 22, 23, 26, 29, 34, 36, 43], and 12 studies examined areas of interest such as scars or trocar insertion points [23–31, 33–35]. Given the technological advances in diagnostic imaging through the last decade, one could surmise that more recently published studies would yield higher diagnostic accuracy than the older ones; however, we found no differences between the included studies when comparing publication or study dates.

The strength of this study is that it provides a comprehensible overview of the available literature on the subject of diagnostic imaging for intra-abdominal adhesions and has been performed as a systematic review in accordance with the PRISMA statement [14]. In addition, the study has been registered prior to its execution on PROSPERO [15], and bias of the included studies was evaluated using a validated assessment tool for diagnostic accuracy studies [16]. A recently published systematic review defining the most effective standard for literature search on surgical studies found that a search strategy similar to this review's, using the same medical databases, yielded more than 98.7% of the relevant literature [44].

The included studies varied greatly in study design, making the results of a pooled analysis questionable. Results from MRI, US, and CT studies could not be pooled due to obvious differences in diagnostic modality, but the US studies alone demonstrated significant differences in their approach to their interpretation of abdominal US. Two studies reported their results as the number of true positives and false negatives recorded in different zones on the abdomen for all patients [27, 29], thus giving a study with 9 zones and 80 patients a total of 720 measurements to be used for the calculation of sensitivity and specificity [29]. Some studies used the combination of different ultrasonic signs to determine the presence of adhesions [22, 28]. There were also differences between studies in the induction of visceral slide, where one study used spontaneous respiration [33] and the remaining used exaggerated respiration [22, 24–26, 28, 30–32, 34, 35]. Moreover, bias analysis revealed important factors in the included studies giving high concerns for risk of bias and lack of applicability, and with the variation in study design, we found that performing a meta-analysis of the US studies was inappropriate. There were too few CT and MRI studies with sufficient and comparable data for a meta-analysis [39, 40, 42].

One major concern in relation to risk of bias is that ten studies included patients without previous surgery or peritonitis, meaning they had very low risk of having adhesions [20, 21, 24–28, 30, 36, 43]. Therefore, the investigator performing the diagnostic test already had a very low suspicion of getting a positive test and could simply do a blind guess of the test being negative, which would yield high accuracy. This is described as a case-control scenario in the QUADAS-2 tool and is a source for bias. Another issue is that only a few studies were double-blinded [19–21, 36, 40, 43]. When the index test is executed with prior knowledge of the result of the reference standard, it interferes with the interpretation and is potential for bias. This is equally valid when the reference standard is interpreted and the result of the index test is known. We found no studies with increased risk of bias, when it came to the flow and timing of their conduct. However, one signaling question dealt with the time interval between index test and reference standard, and here, we decided that the issue was of little concern as we found it very unlikely that adhesions could resolve spontaneously or form in the period between the diagnostic test and surgery. Therefore, ten studies who did not mention the time between test and surgery were not considered at high risk of bias in this domain [19–21, 27, 31, 32, 38–41], neither was a study that did the test 2 to 335 days prior to surgery [43].

In addition to bias assessment, we investigated other factors that could interfere with the interpretation of the included studies' results. Concerns for applicability arise when there is doubt whether the included studies fit the review question. For instance, in the selection of patients, seven studies included patients with ventral hernias [19–21, 23, 38, 40, 43], which might be a concern for both the MRI and US techniques that relied on visceral slide. Since a ventral hernia interferes with the continuity of the abdominal wall and may contain bowel that possibly will not move when visceral slide is induced, it can be suspected that MRI or US might not be applicable on a population with ventral hernias. Likewise, CT diagnosis of adhesions relies on the patient having SBO is a concern for applicability as it only provides data on patients who have a transition zone between dilated and collapsed bowels.

Surgery in patients with abdominal adhesions is associated with increased risk of iatrogenic bowel injury [11], especially during entry in to the peritoneum if bowel is adherent to the abdominal wall [13]. Multiple methods have been proposed to gain entry into the abdominal cavity with laparoscopy, but no method has been proven superior as stated in a recently updated Cochrane review [45]. With diagnostic imaging for adhesions, it may be possible to confirm suspicion of abdominal wall adhesions with the visceral slide technique performed preoperatively and adjust the entry site accordingly, thereby reducing the risk for iatrogenic bowel lesion. Primarily, a radiologist has done the ultrasound exam, although one study has shown that surgeons with no expertise in ultrasound can learn the visceral slide technique with a short training session of no more than 30 min [29]. In addition, preoperative US can be used prior to elective surgery to map the extent of adhesions, so as to properly advise patients of their risk for complications. Both the US and MRI findings also have implications for clinical trials, seeking to assess the presence of adhesions to materials (e.g., meche) implanted during hernia surgery [19–21].

Chronic abdominal pain is a debilitating and costly condition not uncommon in the clinical population [46–48] and has been linked to adhesions in many circumstances [4, 49]. Though there are controversies regarding this subject, it is possible that adhesiolysis could ameliorate symptoms in patients; however, there is insufficient evidence to fully support this procedure for chronic pain [50, 51]. For future clinical practice, diagnostic imaging could elucidate whether there are adhesions, before attempting laparoscopic surgery, and thus, unnecessary procedures could be avoided in patients with no adhesions. Clinical trials enrolling patients undergoing adhesiolysis for pain could also benefit from US or MRI, as they could reduce the risk of laparoscopies where adhesions are not found, which has hampered research earlier [52]. Moreover, diagnostic imaging could help explain whether recurrence of chronic pain is due to adhesion reformation and has potential for the evaluation of adhesion barriers.

Presently, multiple studies have shown that the detection of intra-abdominal adhesions is feasible and accurate with US and MRI. However, a large proportion of the included studies in our review were at risk of bias due to unfavorable selection of patients and lack of blinding. Moreover, the included studies were designed to determine the diagnostic accuracy of imaging techniques leading to a simple yes/no scenario whether there were adhesions present or not. For clinical relevance, it is not sufficient to show the presence of adhesions, but also to determine if these adhesions lead to obstructed bowel passage and chronic pain or increase the risk of bowel injury during subsequent surgery. Further trials are needed to elucidate the clinical relevance of non-invasive imaging techniques for adhesion detection.

Conclusion

US is an accurate modality for the detection of adhesions between viscera and abdominal wall; however, caution is advised when interpreting test results in clinical practice, as there is some variance between available studies and the majority of studies are at risk for bias due to lack of blinding.

MRI studies also had a high and accurate detection of adhesions, but were also limited by the same factors as the US studies.

CT is only suggestible for adhesions in patients with dilated bowels due to SBO and cannot currently be recommended as a diagnostic modality. Further well-designed studies are needed.

Authors' contributions Study conception and design were contributed by JG and FB. Acquisition of the data was contributed by JG and AD. Analysis and interpretation of the data were contributed by JG, AD, and FB. Drafting of the manuscript was contributed by JG. Critical revision of the manuscript was contributed by JG, AD, and FB.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Human and animal rights and informed consent This article does not contain any studies with human participants or animals performed by any of the authors.

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