



# CT IMAGING PREDICTORS OF PATHOLOGIC PNEUMATOSIS INTESTINALIS: A SYSTEMATIC REVIEW AND META-ANALYSIS

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## Article History :

Received date : 2026/07/07

Revised date : 2026/08/23

Accepted date : 2026/09/12

Published date : 2026/10/16



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E-ISSN :

ISSN 3048-1368



P-ISSN

ISSN 3048-1376



## ABSTRACT

**Introduction:** Pneumatosis intestinalis (PI) is a computed tomography (CT) sign rather than a diagnosis, and it spans a spectrum from incidental benign gas to transmural bowel ischaemia and necrosis. Inappropriate interpretation leads either to delayed surgery for necrotic bowel or to non-therapeutic laparotomy. This review aimed to identify and quantify the abdominal CT findings that discriminate pathologic (life-threatening) PI from benign PI.

**Methods:** The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines. Randomized controlled trials, prospective and retrospective cohort, case-control and cross-sectional studies of patients with CT-detected PI that compared CT findings between pathologic PI (transmural ischaemia/necrosis at surgery, pathology or autopsy, PI-related death, or study-defined life-threatening PI) and benign PI were eligible. Risk of bias was assessed with the

Quality In Prognosis Studies (QUIPS) tool and the Newcastle–Ottawa Scale. Odds ratios (OR) were pooled with DerSimonian–Laird random-effects models, with Hartung–Knapp–Sidik–Jonkman, subgroup, leave-one-out and cumulative analyses; small-study effects were examined with funnel plots, Egger and Begg tests and Doi plots. Certainty was rated with GRADE for prognostic factors.

**Results:** Twenty-five cohort studies (4,392 patients) were included; no randomized trials were identified. Twelve studies contributed to meta-analysis. Decreased or absent bowel wall enhancement showed the strongest association with pathologic PI (OR 17.51, 95% CI 1.71–179.17;  $k = 3$ ;  $I^2 = 79\%$ ), followed by mesenteric arterial/venous thrombosis or occlusion (OR 5.26, 95% CI 2.07–13.36;  $k = 3$ ;  $I^2 = 0\%$ ), hepatic portal venous gas (OR 3.48, 95% CI 2.08–5.80;  $k = 7$ ), any portal/portomesenteric venous gas (PMVG) (OR 3.32, 95% CI 2.23–4.96;  $k = 8$ ; 1480 patients;  $I^2 = 48\%$ ), mesenteric venous gas (OR 2.84, 95% CI 1.71–4.72), ascites (OR 2.77, 95% CI 2.09–3.67;  $I^2 = 0\%$ ) and small-bowel location (OR 1.88, 95% CI 1.41–2.52). Isolated foci of PI were associated with benign PI (OR 0.41, 95% CI 0.27–0.62). Pneumoperitoneum (OR 1.02, 95% CI 0.64–1.63), bowel wall thickening (OR 1.25, 95% CI 0.93–1.68), colonic location (OR 0.91, 95% CI 0.70–1.17), bowel dilatation (OR 2.05, 95% CI 0.69–6.09) and multisegment extent (OR 1.68, 95% CI 0.94–3.00) were not significantly associated. PMVG had high specificity (80%) but low sensitivity (45%). Mesenteric fat stranding could not be pooled; it was significantly associated with pathologic PI in 3 of 8 reporting studies. Results were robust in sensitivity analyses, and no small-study effect was detected for PMVG (Egger  $p = 0.91$ ).

**Discussion:** CT findings that reflect compromised mural perfusion (hypoenhancement, vascular occlusion) carry the greatest weight, whereas gas-related findings (PMVG) are specific but insensitive, and pneumoperitoneum alone is not a marker of pathologic PI. Certainty was moderate for PMVG, ascites and small-bowel location and low for hypoenhancement and thrombosis because of heterogeneity and imprecision.

**Conclusion:** A structured CT appraisal of PI should prioritise bowel wall enhancement and mesenteric vascular patency, followed by PMVG, ascites and small-bowel involvement, and must always be integrated with clinical and laboratory red flags. Prospective, protocolised multicentre studies with standardized CT definitions and validated multivariable models are needed.

**Keywords:** pneumatosis intestinalis; portomesenteric venous gas; computed tomography; mesenteric ischemia; bowel necrosis; bowel wall enhancement; meta-analysis

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## INTRODUCTION

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### Background

Pneumatosis intestinalis (PI) denotes the presence of gas within the wall of the gastrointestinal tract, located in the submucosal and/or subserosal layers. With the widespread use of multidetector computed tomography (CT) in emergency, intensive care and oncology settings, PI is now detected far more frequently than in the era of plain radiography, and surgeons and radiologists are increasingly confronted with a finding whose clinical meaning ranges from an incidental, self-limiting phenomenon to the radiological expression of transmural bowel infarction. Current reviews emphasise that PI must be regarded as a sign of an underlying process, not as a disease entity in itself.<sup>1–3</sup>

Three non-mutually exclusive pathogenic mechanisms are generally invoked. The mechanical theory proposes that intraluminal gas dissects into the bowel wall through mucosal breaches under increased intraluminal pressure (obstruction, endoscopy, ileus); the bacterial theory proposes that gas-forming organisms invade a disrupted mucosal barrier, which is typical of ischaemic and infectious injury; and the pulmonary theory proposes that alveolar rupture allows gas to track through the mediastinum and retroperitoneum to the mesentery. In addition, iatrogenic and pharmacological causes—most notably corticosteroids, chemotherapy, targeted agents and transplantation-related immunosuppression—are well recognised causes of benign PI.<sup>1,4,5</sup>

In contrast, pathologic or life-threatening PI is predominantly related to acute mesenteric ischaemia (occlusive arterial, venous or non-occlusive), strangulating obstruction, necrotising infection or perforation, and carries mortality rates that may exceed 40–60% when transmural necrosis is present. In this subgroup, delay in laparotomy and bowel resection is directly linked to death, whereas in benign PI an unnecessary laparotomy exposes frail patients to avoidable morbidity. Multicentre surgical series report that a substantial proportion of patients explored for PI have viable bowel at surgery, illustrating the magnitude of this diagnostic dilemma.<sup>6–9</sup>

CT offers more than the detection of intramural gas. It simultaneously depicts portal and portomesenteric venous gas (PMVG), bowel wall enhancement, the patency of the mesenteric arteries and veins, the location and extent of PI, bowel calibre, mesenteric fat stranding, ascites and extraluminal gas. Each of these ancillary findings has been proposed as a marker of ischaemia, yet individual studies have reported conflicting results—PMVG being

alarming in some cohorts and non-discriminatory in others, and pneumoperitoneum being interpreted variably as an indication for surgery or as a benign accompaniment of cystic PI.<sup>10–</sup>

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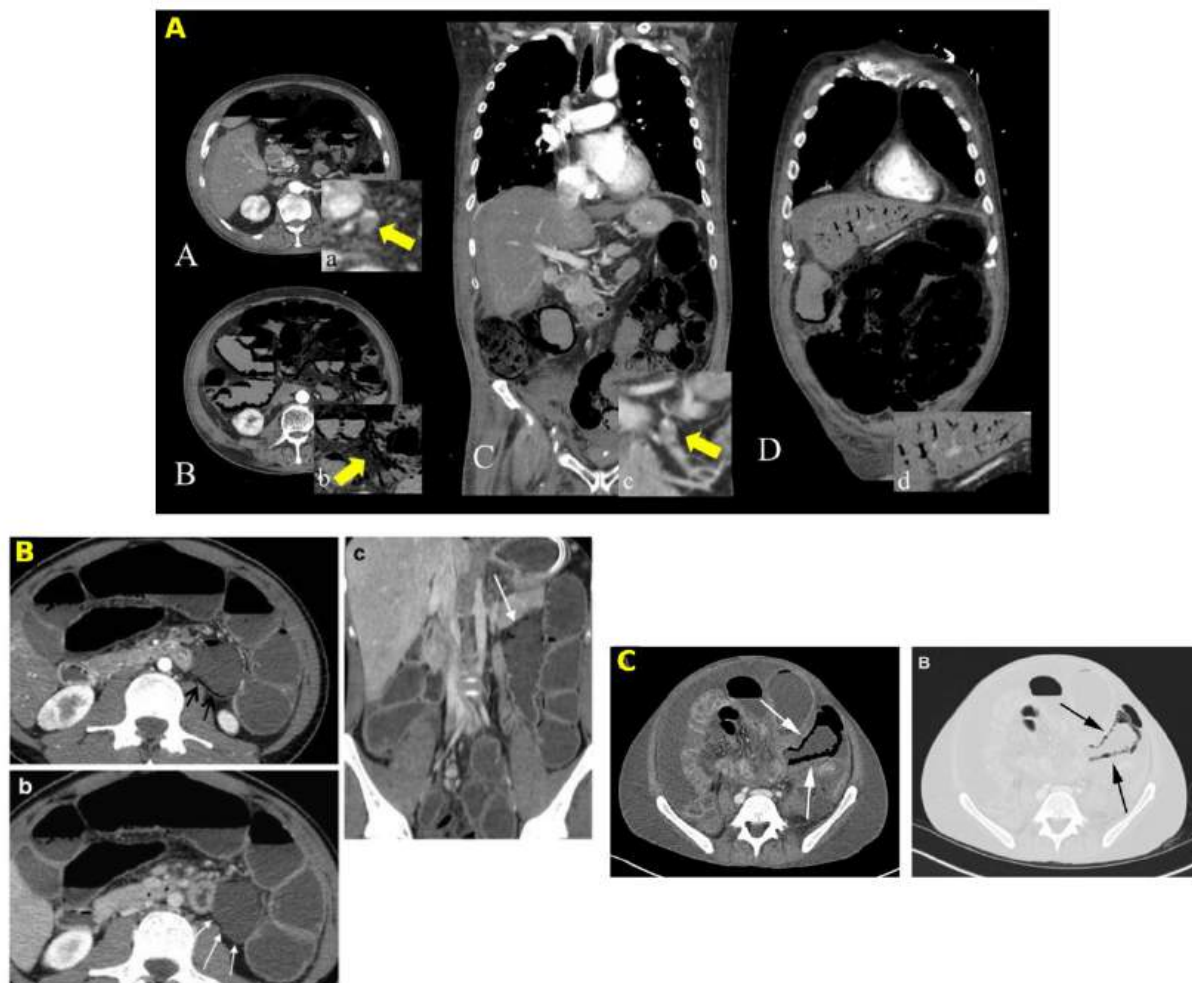


**Figure 1.** Representative CT spectrum of pneumatosis intestinalis. (A) Arterial-phase contrast-enhanced CT in a 68-year-old patient with acute embolic occlusion of the superior mesenteric artery (arrows in a and c), extensive PI and portomesenteric venous gas in the mesenteric veins (b) and intrahepatic portal veins (d); laparotomy revealed extensive intestinal necrosis and the patient died within 24 h. Reproduced from Della Seta et al., *BMC Med Imaging* 2021;21:129 (Fig. 5), CC BY 4.0. (B) Jejunal PI (black arrows) associated with absent mural contrast enhancement (white arrows), indicating acute ischaemia, in a 19-year-old patient with septic shock after J-pouch formation. Reproduced from Treyaud et al., *Eur Radiol* 2017;27:70–79 (Fig. 2), CC BY 4.0. (C) Small-bowel PI (arrows) in soft-tissue and lung windows in a 29-year-old patient with mesenteric venous gas, bowel distension and ascites who recovered completely without resection, illustrating that ancillary findings are not

uniformly ominous. Reproduced from Graber et al., *Abdom Radiol* 2022;47:1625–1635 (Fig. 3), CC BY 4.0.

### **Research gap**

Several research gaps justify the present review. First, the largest prognostic studies of PI were designed by surgical societies and focused primarily on clinical and laboratory predictors (lactate, peritonitis, vasopressor requirement), while the CT findings were reported only descriptively or as secondary variables, so that their independent contribution remains unclear.<sup>6,7,14,15</sup> Second, radiology-led cohorts have used heterogeneous definitions of the reference standard (operative or histological transmural necrosis, PI-related death, "clinically worrisome" or "life-threatening" PI) and different CT definitions, which limits direct comparison.<sup>10–12,16,17</sup> Third, the only directly related meta-analysis addressed radiological predictors of transmural necrosis among patients with established acute mesenteric ischaemia, in whom PI itself was an exposure rather than the defining population; it therefore does not answer the question faced at the bedside, namely how to interpret the ancillary findings once PI has been detected.<sup>18</sup> Fourth, a systematic review of PI induced by anticancer treatment was restricted to case-level data of drug-related PI.<sup>5</sup>

### **Novelty**

To our knowledge, this is the first systematic review and meta-analysis that (i) defines the index population as patients with CT-detected PI, (ii) quantitatively pools the association between each individual CT feature and pathologic PI using study-level 2×2 data extracted from full texts, (iii) complements association measures with pooled sensitivity, specificity and likelihood ratios, (iv) explores heterogeneity through prespecified subgroup, leave-one-out and cumulative analyses, (v) synthesises non-poolable features (such as mesenteric fat stranding and benign-pattern gas morphology) by structured vote counting, and (vi) grades the certainty of evidence for each predictor using the GRADE approach adapted for prognostic factors, translating the results into an evidence-informed CT appraisal pathway.<sup>19</sup>

### **Objectives**

The primary objective was to identify which abdominal CT findings are associated with pathologic PI (transmural ischaemia/necrosis or PI-related life-threatening disease) as opposed to benign PI, and to estimate the strength of these associations. Secondary objectives were (a) to estimate the diagnostic performance (sensitivity, specificity and likelihood ratios) of each CT feature; (b) to evaluate CT findings associated with short-term mortality; (c) to explore sources of heterogeneity; and (d) to rate the certainty of the evidence and propose a practical CT-based risk-stratification framework.

## **Hypotheses**

We hypothesised that CT findings reflecting impaired mural perfusion—decreased or absent bowel wall enhancement and mesenteric arterial or venous occlusion—would show the strongest association with pathologic PI; that portal/portomesenteric venous gas, ascites, small-bowel location and mesenteric fat stranding would show moderate associations; and that findings attributable to gas trapping without ischaemia—isolated cystic foci, pneumoperitoneum and colonic location—would show no association or an inverse association with pathologic PI (null hypothesis: no CT feature differs in frequency between pathologic and benign PI).

## **Expected benefits**

For radiologists, the results support structured reporting of PI with explicit statements on the features that matter most. For surgeons and intensivists, the pooled estimates and likelihood ratios may help calibrate the decision between urgent exploration, short-interval reassessment and conservative management, reducing both missed necrosis and non-therapeutic laparotomy. For researchers, the review identifies the definitional and methodological gaps that future prospective studies and prediction models should address. For health systems, including resource-limited settings, a CT-centred appraisal that prioritises a small number of robust signs can be implemented without additional cost.

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## **METHODS**

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### **Protocol and reporting**

This review was conducted and reported in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 statement.<sup>20</sup> The review questions, eligibility criteria, outcome definitions and analysis plan were defined a priori; the protocol was not prospectively registered, which is acknowledged as a limitation. Because only published aggregate data were analysed, ethical approval and informed consent were not required.

### **Eligibility criteria**

Eligibility criteria were structured according to the PECOS framework. Randomized controlled trials, prospective and retrospective cohort studies, case-control studies and cross-sectional observational studies were eligible. Systematic reviews and meta-analyses were not included in the quantitative synthesis or in the table of study characteristics, but were retrieved for comparison in the Discussion. Only peer-reviewed articles published from

January 2011 onwards (maximum 15 years before the search) were considered, in order to reflect contemporary multidetector CT technology.

**Table 1.** Eligibility criteria (PECOS framework).

| Domain                | Inclusion criteria                                                                                                                                                                                                                                                            | Exclusion criteria                                                                                                                                                                                                    |
|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Population            | Patients (adult or paediatric beyond the neonatal period) with pneumatosis intestinalis detected on abdominal CT, with or without portal/portomesenteric venous gas                                                                                                           | Neonatal necrotising enterocolitis; cohorts defined by another index condition (acute mesenteric ischaemia, bowel obstruction) in which PI was an exposure; cohorts of isolated portal venous gas without PI analysis |
| Exposure (index test) | Any abdominal CT finding: PMVG/portal venous gas, bowel wall enhancement, mesenteric arterial/venous thrombosis, location and extent of PI, gas pattern, ascites/free fluid, bowel dilatation, wall thickening, fat stranding, pneumoperitoneum, retroperitoneal air          | Studies in which PI was diagnosed predominantly by endoscopy or plain radiography                                                                                                                                     |
| Comparator            | Patients with benign PI (no transmural ischaemia/necrosis, conservative recovery, non-PI-related outcome)                                                                                                                                                                     | No comparator group                                                                                                                                                                                                   |
| Outcomes              | Primary: pathologic PI (transmural ischaemia/necrosis at surgery, pathology or autopsy; PI-related death or withdrawal of care; study-defined life-threatening/clinically worrisome PI). Secondary: short-term (in-hospital, 30- or 90-day) mortality; diagnostic performance | Outcomes unrelated to bowel viability or survival (e.g., recurrence only)                                                                                                                                             |
| Study design          | RCT, prospective/retrospective cohort, case-control, cross-sectional                                                                                                                                                                                                          | Case reports, case series < 20 patients without comparison,                                                                                                                                                           |

|  |                                                                                               |                                                                                         |
|--|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
|  | observational studies; peer-reviewed; published 2011–2026; any language with English abstract | narrative reviews, editorials, conference abstracts, preprints; SR/MA (Discussion only) |
|--|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|

## Search Strategy

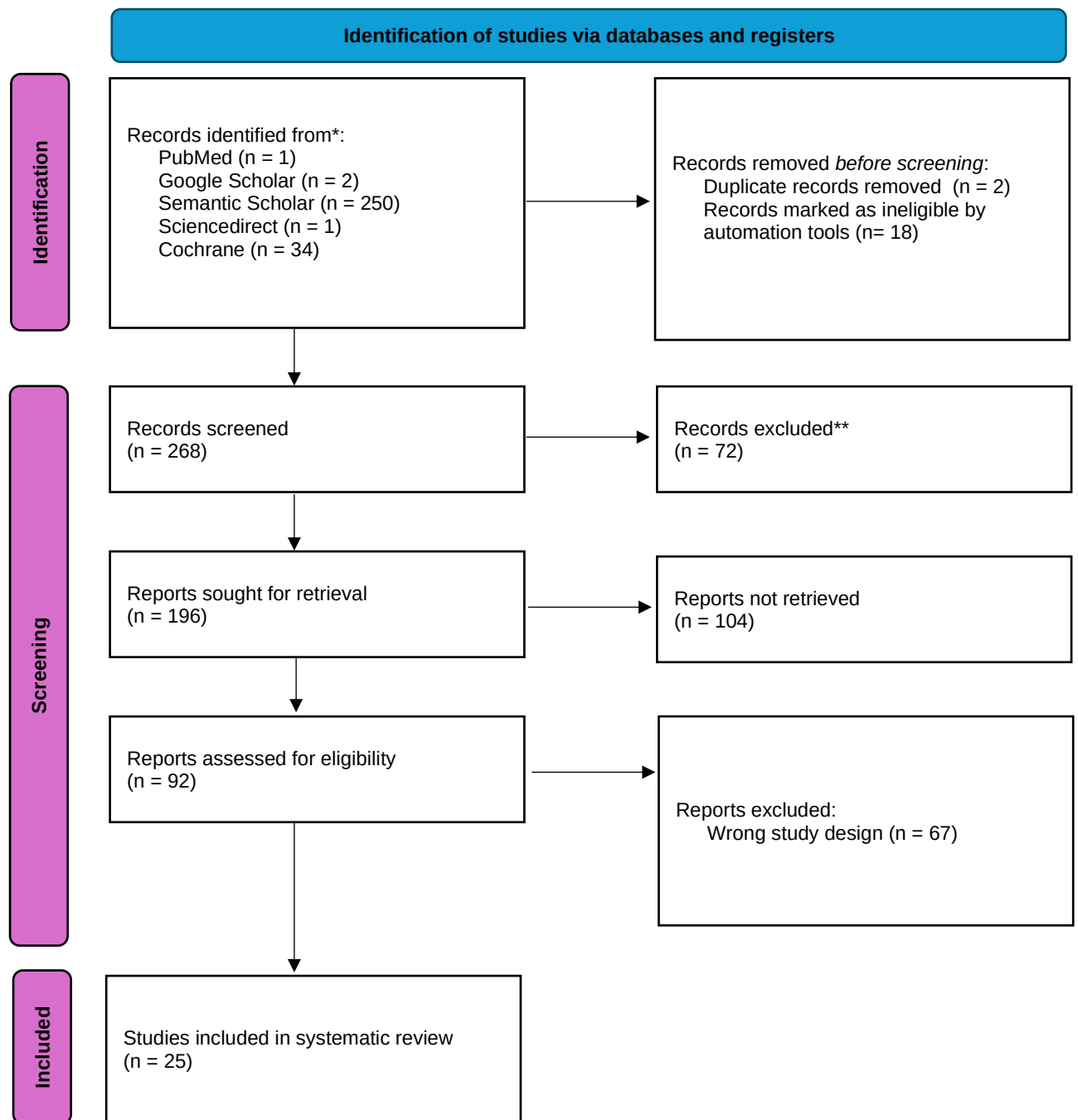
The keywords used for this research based PICO :

| PICO Element                     | Keyword 1                           | Keyword 2                          | Keyword 3                  |
|----------------------------------|-------------------------------------|------------------------------------|----------------------------|
| <b>P — Population</b>            | Pneumatosis intestinalis patients   | CT-detected PI                     | Pathologic vs benign PI    |
| <b>I — Intervention/Exposure</b> | Abdominal CT findings               | Bowel wall enhancement assessment  | Portomesenteric venous gas |
| <b>C — Comparison</b>            | Benign pneumatosis intestinalis     | Conservative management            | Viable bowel at surgery    |
| <b>O — Outcome</b>               | Pathologic pneumatosis intestinalis | Transmural bowel ischemia/necrosis | Short-term mortality       |

The Boolean MeSH keywords inputted on databases for this research are:  
*("Pneumatosis intestinalis patients" OR "CT-detected PI" OR "Pathologic vs benign PI") AND ("Abdominal CT findings" OR "Bowel wall enhancement assessment" OR "Portomesenteric venous gas") AND ("Benign pneumatosis intestinalis" OR "Conservative management" OR "Viable bowel at surgery") AND ("Pathologic pneumatosis intestinalis" OR "Transmural bowel ischemia/necrosis" OR "Short-term mortality")*

## Article Search Strategy

| Database         | Keywords                                                                                                                                                                                                                                                                                                                                                                                                    | Hits |
|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Pubmed           | ("Pneumatosis intestinalis patients" OR "CT-detected PI" OR "Pathologic vs benign PI") AND ("Abdominal CT findings" OR "Bowel wall enhancement assessment" OR "Portomesenteric venous gas" AND "Pathologic pneumatosis intestinalis" OR "Transmural bowel ischemia/necrosis" OR "Short-term mortality")                                                                                                     | 1    |
| Google Scholar   | ("Pneumatosis intestinalis patients" OR "CT-detected PI" OR "Pathologic vs benign PI" AND "Abdominal CT findings" OR "Bowel wall enhancement assessment" OR "Portomesenteric venous gas" AND "Pathologic pneumatosis intestinalis" OR "Transmural bowel ischemia/necrosis" OR "Short-term mortality")                                                                                                       | 2    |
| Semantic Scholar | ("Pneumatosis intestinalis patients" OR "CT-detected PI" OR "Pathologic vs benign PI") AND ("Abdominal CT findings" OR "Bowel wall enhancement assessment" OR "Portomesenteric venous gas") AND ("Benign pneumatosis intestinalis" OR "Conservative management" OR "Viable bowel at surgery") AND ("Pathologic pneumatosis intestinalis" OR "Transmural bowel ischemia/necrosis" OR "Short-term mortality") | 250  |
| Science-direct   | ("Pneumatosis intestinalis patients" AND "Abdominal CT findings" OR "Bowel wall enhancement assessment" OR "Portomesenteric venous gas" AND "Pathologic pneumatosis intestinalis" OR "Transmural bowel ischemia/necrosis" OR "Short-term mortality")                                                                                                                                                        | 1    |
| Cochrane         | ("Pneumatosis intestinalis patients" OR "CT-detected PI" OR "Pathologic vs benign PI" AND "Abdominal CT findings" OR "Bowel wall enhancement assessment" OR "Portomesenteric venous gas" AND "Pathologic pneumatosis intestinalis" OR "Transmural bowel ischemia/necrosis" OR "Short-term mortality")                                                                                                       | 34   |



**Article search flowchart**

### Study selection

Records were de-duplicated and screened on title and abstract, followed by full-text (or, where the full text could not be accessed, abstract-level) assessment against the eligibility criteria. Reasons for exclusion at the full-text stage were recorded. Studies for which only the abstract was accessible were retained in the qualitative synthesis when eligibility and the direction of association of the CT findings could be established, and were included in meta-analysis only when extractable 2×2 data were available.

## **Data extraction and data items**

A standardised extraction form captured: first author, year, country, design (prospective/retrospective; single-/multicentre), setting, study period, sample size, age and sex, population characteristics (PI-only cohort versus PI and/or PVG cohort; adult/paediatric; oncology), CT technique (contrast phases, readers, blinding), reference standard and outcome definition, number of patients with pathologic and benign PI, and the frequency of each CT feature in each group. Univariable odds ratios were computed from 2×2 tables; multivariable-adjusted estimates were extracted separately and summarised descriptively because covariate sets differed between studies.

Three specific data-handling decisions were prespecified. (1) For Treyaud et al., group-wise counts of PMVG were not reported; the 2×2 table was reconstructed from the reported  $\chi^2$  statistic and marginal totals (80 ischaemic versus 69 non-ischaemic patients; 48 with PMVG), yielding 35/80 versus 13/69 (reconstructed  $\chi^2 = 10.5$  versus reported 10.75), and the influence of this reconstruction was tested in sensitivity analysis.<sup>10</sup> (2) For Fleck et al., only the laparotomy subgroup (n = 82) could be extracted from the reported rates of non-therapeutic laparotomy according to enhancement category.<sup>9</sup> (3) When several definitions of the same feature were reported, the broadest clinically equivalent definition was used for the main analysis (for example, "vascular gas" for PMVG in DuBose et al., and moderate multisegment plus extensive diffuse air for extent), and alternative definitions (strict hepatic portal venous gas) were analysed separately.<sup>6</sup> Studies reporting mortality rather than pathologic PI were analysed under the secondary outcome.

## **Outcome definitions**

Pathologic PI was defined as PI associated with transmural ischaemia, necrosis or perforation confirmed at surgery, endoscopy, histopathology or autopsy, or PI followed by death attributable to the underlying bowel process (including withdrawal of care) before confirmation, or the study-specific category of "life-threatening" or "clinically worrisome" PI. Benign PI comprised patients managed conservatively with clinical or radiological resolution, patients with viable bowel at exploration, and patients whose death was unrelated to PI. Short-term mortality was defined as in-hospital, 30-day or 90-day all-cause mortality as reported.

## **Risk of bias assessment**

Because the review question concerns the prognostic and discriminatory value of CT features, risk of bias was assessed with the Quality In Prognosis Studies (QUIPS) tool across six domains: study participation, study attrition, prognostic factor (CT) measurement,

outcome measurement, study confounding, and statistical analysis and reporting; each domain was rated as low, moderate or high risk.<sup>21</sup> An overall rating was assigned a priori as low (no high-risk domain and  $\leq 2$  moderate domains), moderate ( $\geq 3$  moderate domains or a single high-risk domain limited to confounding), or high (high risk in participation, CT measurement or outcome measurement, or  $\geq 2$  high-risk domains). Methodological quality was additionally scored with the Newcastle–Ottawa Scale (NOS; 0–9 stars;  $\geq 7$  considered good quality).<sup>22</sup>

### **Risk of bias and methodological quality**

Risk of bias according to QUIPS is summarised in Table 5 and Figures 3 and 4. Overall risk of bias was low in two studies, moderate in eight and high in two. The domains most frequently at moderate or high risk were study confounding—because CT features were analysed univariably in most studies—and prognostic factor measurement, because several large multicentre studies relied on non-standardised attending radiologist reports rather than blinded re-reading. Outcome measurement was at high risk in one study that classified patients by clinical presentation rather than by operative or pathological confirmation, and statistical analysis was at high risk in one very small cohort. NOS scores ranged from 5 to 8 stars (median 7); nine of twelve studies were of good quality ( $\geq 7$  stars).<sup>13,21,22,39</sup>

**Table 2.** Risk of bias (QUIPS) and methodological quality (Newcastle–Ottawa Scale) of the quantitatively synthesised studies.

| Study           | Parti<br>ci-<br>patio<br>n | Attri<br>- tion | CT<br>meas<br>ure-<br>ment | Outc<br>ome<br>meas<br>ure-<br>ment | Conf<br>ound<br>-ing | Anal<br>ysis/<br>repo<br>rting | Over<br>all  | N<br>OS<br>(0–<br>9) | Main<br>concern                                                            |
|-----------------|----------------------------|-----------------|----------------------------|-------------------------------------|----------------------|--------------------------------|--------------|----------------------|----------------------------------------------------------------------------|
| DuBose<br>2013  | Low                        | Mod             | Mod                        | Mod                                 | High                 | Low                            | Mode<br>rate | 7                    | Withdrawal of<br>care counted<br>as pathologic;<br>reports not re-<br>read |
| Ferrada<br>2017 | Low                        | Mod             | Mod                        | Mod                                 | Mod                  | Low                            | Mode<br>rate | 7                    | Missing data<br>in 47/127 for<br>modelling                                 |
| Treyaud         | Low                        | Low             | Mod                        | Mod                                 | High                 | Mod                            | Mode         | 7                    | 31% non-                                                                   |

|                  |     |     |     |      |      |      |              |   |                                                      |
|------------------|-----|-----|-----|------|------|------|--------------|---|------------------------------------------------------|
| 2017             |     |     |     |      |      |      | rate         |   | enhanced CT;<br>counts<br>reconstructed              |
| Ko 2018          | Mod | Low | Low | High | High | Mod  | High         | 5 | Groups<br>defined by<br>clinical<br>presentation     |
| Higashizono 2016 | Mod | Low | Mod | Mod  | High | Mod  | Mode<br>rate | 7 | Conservative<br>group<br>unconfirmed;<br>overfitting |
| Muratsu 2020     | Mod | Low | Low | Mod  | High | High | High         | 6 | n = 25; sparse<br>data                               |
| Song 2025        | Mod | Low | Mod | Low  | Low  | Low  | Low          | 8 | Comfort care<br>and vaso-<br>occlusion<br>excluded   |
| Moore 2026       | Low | Low | Mod | Low  | High | Low  | Mode<br>rate | 7 | Univariable<br>CT analysis<br>only                   |
| Fleck 2024       | Low | Low | Low | Low  | Low  | Mod  | Low          | 8 | Laparotomy<br>subgroup<br>only; very<br>wide CI      |
| Graber 2022      | Mod | Mod | Low | Low  | Mod  | Mod  | Mode<br>rate | 6 | Suspected<br>AMI only;<br>consent<br>exclusions      |
| Della Seta 2021  | Low | Low | Mod | Low  | Mod  | Mod  | Mode<br>rate | 8 | Mortality<br>outcome;<br>heterogeneous<br>aetiology  |
| Wong 2024        | Low | Low | Mod | Low  | Mod  | Mod  | Mode         | 8 | PI and/or                                            |

|  |  |  |  |  |  |  |      |  |                              |
|--|--|--|--|--|--|--|------|--|------------------------------|
|  |  |  |  |  |  |  | rate |  | PVG cohort;<br>abstract data |
|--|--|--|--|--|--|--|------|--|------------------------------|

*Mod, moderate. Overall rating rule prespecified in Section 2.7.*

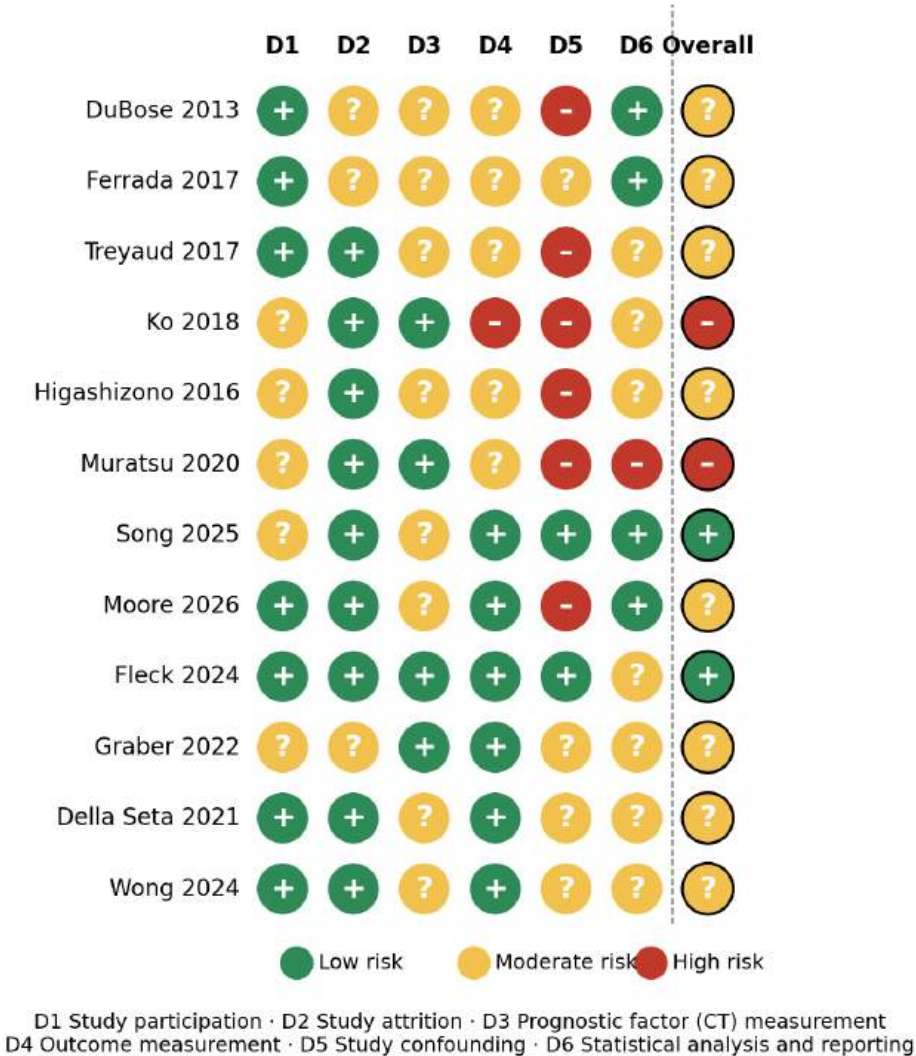


**Figure 2.** Risk-of-bias traffic-light plot (QUIPS) for the 12 quantitatively synthesised studies. Green (+), low; yellow (?), moderate; red (–), high risk of bias.

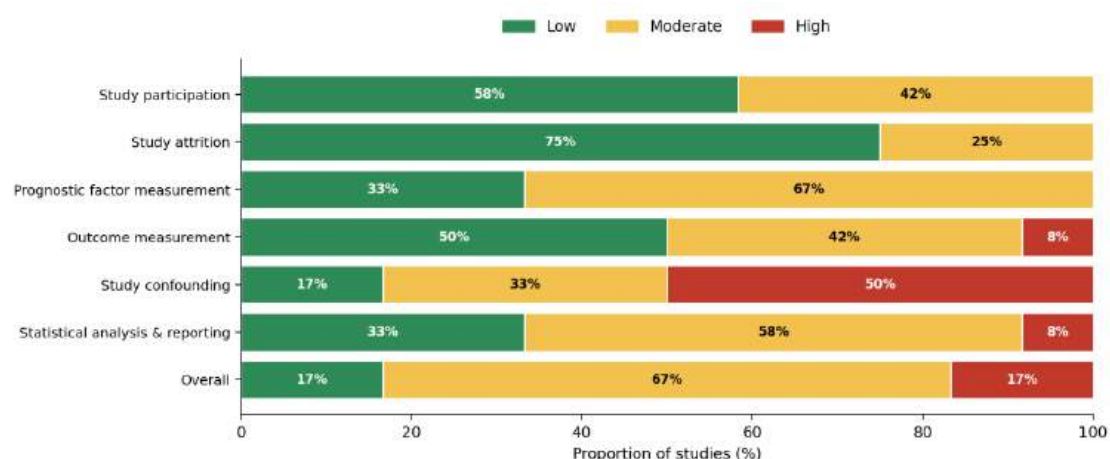


**Figure 3.** Summary of risk-of-bias judgements across QUIPS domains, expressed as the proportion of studies at low, moderate and high risk.

### Effect measures and synthesis methods

The odds ratio (OR) with 95% confidence interval (CI) was the principal effect measure; a continuity correction of 0.5 was applied to all cells of tables containing a zero cell. Meta-analysis was performed for every CT feature reported by at least two studies, using the DerSimonian–Laird random-effects model, and fixed-effect (inverse-variance) estimates were calculated for comparison.<sup>23</sup> Because the DerSimonian–Laird approach may underestimate uncertainty when few studies are available, the Hartung–Knapp–Sidik–Jonkman (HKSJ) adjustment was applied as a sensitivity analysis. Heterogeneity was quantified with Cochran's  $Q$ ,  $\tau^2$  and the  $I^2$  statistic ( $I^2 \leq 25\%$  low, 25–75% moderate,  $> 75\%$  high), and 95% prediction intervals were calculated for analyses with  $\geq 5$  studies.<sup>24</sup>

Pooled sensitivity and specificity were obtained by random-effects pooling of logit-transformed proportions, and positive and negative likelihood ratios (LR+ and LR–) were derived from the pooled estimates; individual and pooled estimates were displayed in paired forest plots and in receiver operating characteristic (ROC) space. Studies reporting mortality were pooled separately; where only an OR with 95% CI was reported, the generic inverse-variance method was used. Estimates of several CT features derived from one study were displayed but not pooled because they are not independent. All analyses were performed with custom, validated scripts in Python 3 (NumPy, SciPy and Matplotlib).

### Heterogeneity, subgroup and sensitivity analyses

For the most frequently reported predictor (PMVG), prespecified subgroup analyses were performed by study population (PI-only versus PI and/or PVG cohorts), design (multicentre versus single-centre), geographic region (North America, Europe, East Asia) and reference standard (operative/autopsy-confirmed necrosis, composite operative-or-death

outcome, clinical/aetiological classification); differences between subgroups were tested with the Q-between statistic. Sensitivity analyses comprised leave-one-out analysis, cumulative meta-analysis by publication year, exclusion of reconstructed data, exclusion of high risk-of-bias studies, restriction to strict hepatic portal venous gas, fixed-effect modelling and HKSJ adjustment. Analogous sensitivity analyses were performed for ascites, small-bowel location and pneumoperitoneum.

### **Assessment of small-study effects and reporting bias**

For analyses including at least five studies, small-study effects were explored with contour-enhanced funnel plots, Egger's regression test and Begg's rank correlation test, recognising their low power with fewer than ten studies.<sup>25</sup> Doi plots and the Luis Furuya-Kanamori (LFK) index were additionally computed for PMVG and ascites, with  $|LFK| \leq 1$  indicating no asymmetry, 1–2 minor asymmetry and  $> 2$  major asymmetry.<sup>26</sup>

### **Narrative synthesis of non-poolable data**

CT features without extractable 2×2 data in at least two studies (for example, mesenteric fat stranding) and studies with abstract-level data only were synthesised by structured vote counting based on the direction and statistical significance of the reported association, displayed as a harvest-style heat map.

### **Certainty of evidence**

The certainty of evidence for each CT predictor was rated with the GRADE approach for prognostic factors, in which a body of observational cohort evidence starts at high certainty and is rated down for risk of bias, inconsistency, imprecision, indirectness and publication bias, and may be rated up for a large magnitude of association.<sup>19</sup>

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## **RESULTS**

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### **Characteristics of included studies**

All were observational cohort studies: one was prospective and multicentre (Ferrada et al., seven centres in the United States and Brazil), and 24 were retrospective, of which seven were multicentre or multi-hospital. Studies were conducted in North America (n = 12), East Asia (Japan, Korea, Taiwan and China; n = 8), Europe (Switzerland, Germany and France; n = 4) and Australia (n = 1). Publication years ranged from 2011 to 2026, with 15 studies (60%) published from 2020 onwards. Sample sizes ranged from 25 to 500 patients (median 149). One study was paediatric and one was confined to patients with cancer.<sup>6,7,11,15,17,37</sup>

The prevalence of pathologic PI varied widely, from 7.2% in children beyond the neonatal period and 20.7% in a cohort that excluded vaso-occlusive disease and comfort care, to 53.7% in emergency patients and 66.5% in a predominantly inpatient Taiwanese cohort, reflecting differences in case mix, referral pattern and outcome definition. Reference standards ranged from operative or autopsy-confirmed transmural necrosis to composite definitions including death before surgery or withdrawal of care, and to clinical classification as life-threatening or clinically worrisome PI.<sup>6,10,12,15,16,37</sup>

**Table 3.** Characteristics of the 25 included studies (ordered by contribution to the synthesis).

| Study [ref]                | Country                 | Design / setting                         | Period           | N   | Pathologic / outcome-positive, n (%) | Reference standard / outcome                                              | CT features analysed                                                                                      | Synthesis |
|----------------------------|-------------------------|------------------------------------------|------------------|-----|--------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|-----------|
| DuBose 2013 <sup>6</sup>   | USA (8 centres)         | Retrospective cohort, multicentre        | 2001–2010        | 500 | 201 (40.2)                           | Transmural ischaemia at surgery/endoscopy or withdrawal of care and death | Location, pattern, extent, PMVG/HPVG, ascites, dilatation, thickening, occlusion, free gas                | MA        |
| Ferrada 2017 <sup>7</sup>  | USA, Brazil (7 centres) | Prospective cohort, multicentre          | 3-year enrolment | 127 | 48 (37.8)                            | Transmural ischaemia at surgery or autopsy                                | Location, diffuse PI, HPVG, PMVG, ascites, dilatation, thickening, occlusion, free air                    | MA        |
| Treyaud 2017 <sup>10</sup> | Switzerland             | Retrospective cohort, emergency patients | NR               | 149 | 80 (53.7)                            | Ischaemic aetiology (histology in 61%; clinical/surgical)                 | Location, extension, PMVG distribution, enhancement, thickening, dilatation, stranding, fluid, thrombosis | MA        |
| Ko 2018 <sup>13</sup>      | Korea                   | Retrospective cohort, single             | 2006–2015        | 42  | 18 (42.9)                            | Life-threatening PI (clinical status,                                     | Distension, enhancement, wall defect, PVG, MVG,                                                           | MA        |

|                                |                             |                                     |           |                     |           |                                                                  |                                                                  |     |
|--------------------------------|-----------------------------|-------------------------------------|-----------|---------------------|-----------|------------------------------------------------------------------|------------------------------------------------------------------|-----|
|                                |                             | centre                              |           |                     |           | surgery, death)                                                  | free air, ascites                                                |     |
| Higashizono 2016 <sup>38</sup> | Japan                       | Retrospective cohort, single centre | 2002–2014 | 52*                 | 17 (32.7) | Bowel necrosis at surgery/pathology/autopsy                      | PVG (lobe), PI pattern, enhancement, ascites, free air           | MA  |
| Muratsu 2020 <sup>39</sup>     | Japan                       | Retrospective cohort, ED/ICU        | 2013–2017 | 25*                 | 18 (72.0) | Bowel necrosis                                                   | HPVG quantity/distribution, PI type, free air, ascites           | MA  |
| Song 2025 <sup>15</sup>        | USA (2 centres)             | Retrospective cohort, multicentre   | 2010–2020 | 334                 | 69 (20.7) | Ischaemic/perforated bowel at laparotomy or death before surgery | Location, foci, multisegment, thickening, PVG, free air, ascites | MA  |
| Moore 2026 <sup>8</sup>        | USA (multi-hospital system) | Retrospective cohort                | NR        | 252                 | 90 (35.7) | Non-viable bowel at surgery                                      | PVG, free air, location (CT–operative concordance)               | MA  |
| Fleck 2024 <sup>9</sup>        | France                      | Retrospective cohort, single centre | 2012–2021 | 226 (82 laparotomy) | 78 (34.5) | Resection for ischaemia or death from ischaemia                  | Bowel wall enhancement (normal/doubtful/absent)                  | MA† |
| Graber 2022 <sup>40</sup>      | Switzerland                 | Retrospective                       | 2014–     | 109                 | 71 deaths | 30-day mortality                                                 | Location, venous gas,                                            | MA  |

|                                  |                           |                                                  |               |      |                      |                                                       |                                                                                                                  |                   |
|----------------------------------|---------------------------|--------------------------------------------------|---------------|------|----------------------|-------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|-------------------|
|                                  |                           | cohort<br>(suspected<br>AMI)                     | 2019          |      | (65.1)               |                                                       | enhancement, distension,<br>oedema, ascites, solid-organ<br>perfusion                                            | (mortality)       |
| Della Seta<br>2021 <sup>41</sup> | Germany (3<br>centres)    | Retrospective<br>cohort,<br>multicentre          | 2008–<br>2018 | 290  | 160 deaths<br>(55.2) | 90-day mortality                                      | PMVG, length of PI,<br>vascular disorders                                                                        | MA<br>(mortality) |
| Wong 2024 <sup>42</sup>          | Australia                 | Retrospective<br>cohort,<br>quaternary<br>centre | 2013–<br>2021 | 107* | 33 deaths<br>(30.8)  | Mortality; surgery                                    | PI + PVG, free fluid,<br>perforation                                                                             | MA<br>(mortality) |
| Lee KS 2013<br><sup>11</sup>     | USA<br>(cancer<br>centre) | Retrospective<br>cohort,<br>oncology             | NR            | 84   | 37 (44.0)            | Clinically worrisome<br>PI                            | Location, pattern, PMVG,<br>thickening, dilatation,<br>stranding, ascites,<br>pneumoperitoneum                   | QS                |
| Goyal 2017 <sup>12</sup>         | USA                       | Retrospective<br>cohort                          | 2011–<br>2013 | 141  | 44 (31.2)            | Dead bowel at<br>surgery or death<br>during admission | Location, pattern, dilatation,<br>thickening, enhancement,<br>stranding, PV/MV gas,<br>oedema, free air, ascites | QS                |
| Lu 2026 <sup>16</sup>            | Taiwan                    | Retrospective<br>cohort                          | 2013–<br>2022 | 215  | 143 (66.5)           | Life-threatening PI<br>(clinical outcome)             | Location, extent,<br>circumferential gas,<br>mesenteric pneumatosis,                                             | QS                |

|                              |                        |                                            |           |      |                |                                                                      |                                                                    |    |
|------------------------------|------------------------|--------------------------------------------|-----------|------|----------------|----------------------------------------------------------------------|--------------------------------------------------------------------|----|
|                              |                        |                                            |           |      |                |                                                                      | PMVG, enhancement, dilatation, stranding, free air/fluid           |    |
| Rigioli 2025 <sup>17</sup>   | USA                    | Retrospective cohort                       | 2002–2018 | 313  | 114 (36.4)     | Ischaemic bowel at surgery or ischaemia-related death $\leq$ 30 days | Thrombosis, PMVG, stranding, location; clinical–radiological model | QS |
| Bani Hani 2013 <sup>43</sup> | USA (multicentre)      | Retrospective cohort                       | NR        | 209* | NR             | Bowel ischaemia/necrosis                                             | PN/PVG, ascites, stranding, thickening, PN type                    | QS |
| Duron 2011 <sup>44</sup>     | USA (2 hospitals)      | Retrospective cohort                       | NR        | 150  | 63/72 operated | Positive operative findings                                          | Dilated loops, PVG, atherosclerosis                                | QS |
| Rieser 2021 <sup>14</sup>    | USA (hospital network) | Retrospective derivation–validation cohort | 2010–2016 | 305  | 102 (33.4)     | Pathologic PI                                                        | Small-bowel PI within five-factor score                            | QS |
| Clancy 2021 <sup>45</sup>    | USA                    | Retrospective cohort (machine learning)    | NR        | 300  | NR             | Pathologic PI; need for operation                                    | CT radiomic features                                               | QS |
| Lee HS 2014                  | Korea                  | Retrospective                              | NR        | 123  | 29 deaths      | Disease-related in-                                                  | Wall enhancement and                                               | QS |

|                            |                  |                                         |           |     |           |                                                             |                                                                      |    |
|----------------------------|------------------|-----------------------------------------|-----------|-----|-----------|-------------------------------------------------------------|----------------------------------------------------------------------|----|
| <sup>46</sup>              |                  | cohort                                  |           |     | (23.6)    | hospital mortality                                          | clinical signs (mortality score)                                     |    |
| Fujii 2021 <sup>47</sup>   | Japan            | Retrospective cohort                    | 2009–2019 | 64  | 15 (23.4) | Bowel ischaemia                                             | Ascites, free air, HPVG                                              | QS |
| Yoshida 2024 <sup>48</sup> | Japan            | Retrospective cohort                    | NR        | 50* | 16 (32.0) | Surgery or inoperable surgical indication (high-risk group) | Enhancement, stranding, intra-/extrahepatic PVG                      | QS |
| He 2026 <sup>49</sup>      | China            | Retrospective cohort                    | NR        | 58  | 10 (17.2) | Surgical treatment                                          | Location, morphology, ascites, PMVG, enhancement, dilatation, oedema | QS |
| Abramov 2022 <sup>37</sup> | USA (paediatric) | Retrospective cohort, 3 months–18 years | NR        | 167 | 12 (7.2)  | Irreversible transmural ischaemia                           | PVG, bowel distension                                                | QS |

\*Cohort of PI and/or portal venous gas. †Laparotomy subgroup extracted from the abstract. AMI, acute mesenteric ischaemia; ED, emergency department; HPVG, hepatic portal venous gas; ICU, intensive care unit; MA, meta-analysis; MV, mesenteric venous; NR, not reported in the accessible report; PMVG, portomesenteric venous gas; PN, pneumatosis; PV(G), portal venous (gas); QS, qualitative synthesis only.

**Table 4.** CT technique, image interpretation and reference standard in the 12 quantitatively synthesised studies.

| Study | CT technique | Image interpretation | Blinded to outcome | Reference standard |
|-------|--------------|----------------------|--------------------|--------------------|
|-------|--------------|----------------------|--------------------|--------------------|

|                  |                                                                 |                                                    |         |                                                                         |
|------------------|-----------------------------------------------------------------|----------------------------------------------------|---------|-------------------------------------------------------------------------|
| DuBose 2013      | CT in 96%, plain radiography in 4%; non-standardised            | Attending radiologist reports                      | No      | Operative/endoscopic transmural ischaemia or withdrawal of care + death |
| Ferrada 2017     | CT in 92%; protocol not standardised                            | Attending radiologist reports                      | No      | Operative or autopsy transmural ischaemia                               |
| Treyaud 2017     | MDCT; IV contrast in 69% (arterial + venous in 38 patients)     | Two radiologists, joint review                     | Partial | Final diagnosis (histology in 61%)                                      |
| Ko 2018          | 64-row MDCT; contrast in 40/42                                  | Two radiologists, independent                      | Yes     | Clinical group (presentation, treatment, outcome)                       |
| Higashizono 2016 | Contrast-enhanced CT; PVG within 2 cm of liver capsule          | Radiology report database                          | No      | Surgery, pathology or autopsy                                           |
| Muratsu 2020     | CT; HPVG quantity by region                                     | Retrospective image review                         | NR      | Bowel necrosis (surgery/clinical)                                       |
| Song 2025        | Abdominopelvic CT; vaso-occlusive cases excluded                | Report and chart review                            | No      | Laparotomy findings or death before surgery                             |
| Moore 2026       | CT in multi-hospital system                                     | EHR radiology reports; CT–operative concordance    | No      | Operative non-viable bowel                                              |
| Fleck 2024       | Contrast-enhanced CT                                            | Two blinded readers + third reader for discordance | Yes     | Resection for ischaemia or ischaemic death                              |
| Graber 2022      | Dual-source CT: non-enhanced, arterial and portal-venous phases | Two blinded readers; consensus in 10%              | Yes     | 30-day mortality                                                        |
| Della Seta       | Contrast-enhanced CT                                            | Re-reading by radiologists at                      | NR      | 90-day mortality                                                        |

|           |                            |                   |    |                    |
|-----------|----------------------------|-------------------|----|--------------------|
| 2021      | (arterial/portal-venous)   | each centre       |    |                    |
| Wong 2024 | CT (16,428 scans screened) | Radiology reports | NR | Mortality; surgery |

*EHR, electronic health record; IV, intravenous; MDCT, multidetector CT; NR, not reported.*

### Frequency of CT findings in pathologic and benign PI

Across the nine studies contributing to the primary outcome, 541 of 1,480 patients (36.6%) with available PMVG data had pathologic PI. PMVG was present in 234/541 (43.3%) patients with pathologic PI versus 178/939 (19.0%) with benign PI, and ascites in 187/371 (50.4%) versus 190/709 (26.8%) patients, respectively.

**Table 5.** Frequency of CT findings in pathologic versus benign PI in individual studies (n/N pathologic vs n/N benign).

| Study            | PMVG             | Decreased enhancement | Vascular occlusion | Ascites           | Bowel dilatation   | Wall thickening  | Small-bowel location | Pneumo-peritoneum |
|------------------|------------------|-----------------------|--------------------|-------------------|--------------------|------------------|----------------------|-------------------|
| DuBose 2013      | 75/201 vs 44/299 | —                     | 10/201 vs 2/298    | 108/201 vs 82/299 | 115/201 vs 167/299 | 64/201 vs 87/299 | 87/201 vs 66/298     | 45/201 vs 54/299  |
| Ferrada 2017     | 16/48 vs 6/79    | —                     | 3/48 vs 2/79       | 9/48 vs 8/79      | 23/48 vs 36/79     | 17/48 vs 22/79   | 29/48 vs 32/79       | 10/48 vs 14/79    |
| Treyaud 2017     | 35/80 vs 13/69   | —                     | 12/80 vs 2/69      | —                 | —                  | —                | 42/80 vs 26/69       | —                 |
| Ko 2018          | 8/18 vs 0/24     | 14/18 vs 1/22         | —                  | 13/18 vs 7/24     | 15/18 vs 5/24      | —                | —                    | 11/18 vs 13/24    |
| Higashizono 2016 | 9/17 vs 11/35    | 8/17 vs 9/35          | —                  | 10/17 vs 8/35     | —                  | —                | —                    | 5/17 vs 15/35     |
| Muratsu          | 12/18 vs         | —                     | —                  | 15/18             | —                  | —                | —                    | 1/18 vs           |

|               |                    |                      |   |                       |   |                       |                        |                       |
|---------------|--------------------|----------------------|---|-----------------------|---|-----------------------|------------------------|-----------------------|
| 2020          | 6/7                |                      |   | vs 6/7                |   |                       |                        | 5/7                   |
| Song 2025     | 35/69 vs<br>46/265 | —                    | — | 32/69<br>vs<br>79/265 | — | 25/69<br>vs<br>75/265 | 35/69<br>vs<br>112/265 | 7/69 vs<br>33/265     |
| Moore<br>2026 | 44/90 vs<br>52/161 | —                    | — | —                     | — | —                     | 53/90<br>vs<br>82/162  | 34/90<br>vs<br>45/162 |
| Fleck<br>2024 | —                  | 48/49<br>vs<br>17/33 | — | —                     | — | —                     | —                      | —                     |

— not reported or not extractable. DuBose small-bowel location refers to ileal PI. Fleck: laparotomy subgroup.

### Primary outcome: CT predictors of pathologic PI

#### Portal and portomesenteric venous gas

PMVG was the most frequently evaluated predictor (eight studies; 1480 patients). PMVG was associated with a more than threefold increase in the odds of pathologic PI (OR 3.32, 95% CI 2.23–4.96;  $p < 0.001$ ), with moderate heterogeneity ( $I^2 = 48\%$ ;  $\tau^2 = 0.135$ ;  $p(Q) = 0.064$ ) and a 95% prediction interval of 1.19 to 9.30, indicating that the association is expected to persist in a future comparable cohort (Figure 5). Seven of eight studies showed point estimates above 1; the exception was a small cohort composed of patients with hepatic portal venous gas and/or PI, in which almost all patients had venous gas by design.<sup>6–8,10,15,39</sup>

Portal and/or portomesenteric venous gas vs. pathologic PI

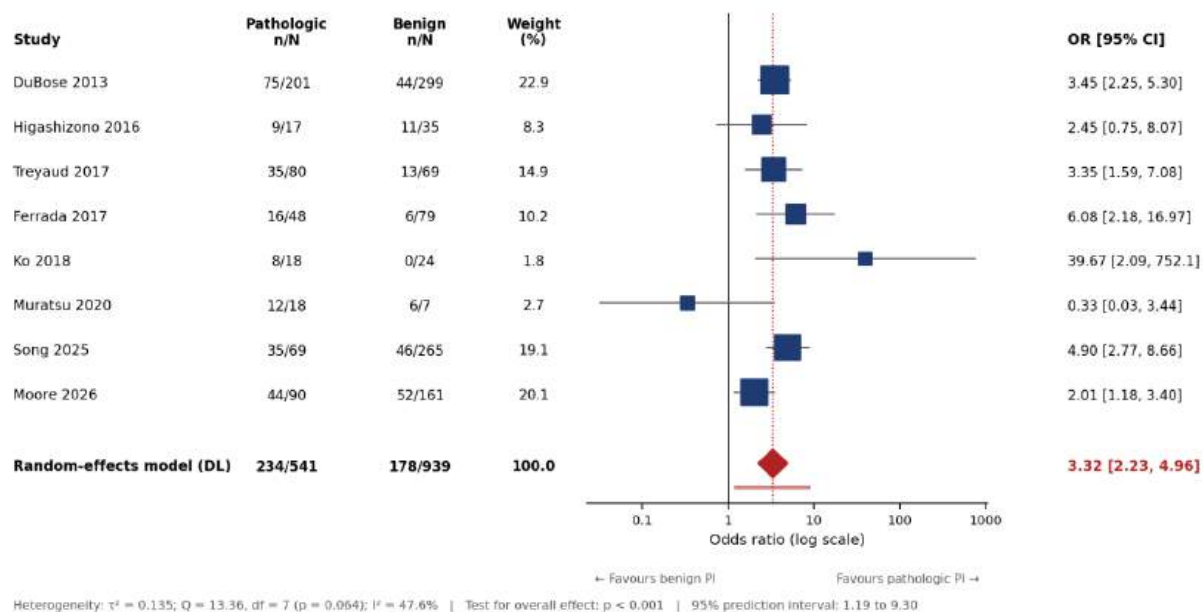


**Figure 4.** Forest plot of the association between portal and/or portomesenteric venous gas and pathologic PI (random-effects model). The red bar beneath the diamond represents the 95% prediction interval.

When restricted to the strict definition of hepatic portal venous gas (seven studies; 1331 patients), the pooled estimate was similar (OR 3.48, 95% CI 2.08–5.80;  $I^2 = 57\%$ ;  $\tau^2 = 0.226$ ;  $p(Q) = 0.029$ ). Gas confined to the mesenteric veins was evaluated in three studies and was also associated with pathologic PI (OR 2.84, 95% CI 1.71–4.72;  $I^2 = 24\%$ ;  $\tau^2 = 0.054$ ;  $p(Q) = 0.269$ ). Within individual studies, the anatomical distribution and quantity of venous gas carried additional information: gas in the segmental mesenteric veins and the extrahepatic portal vein, gas involving more than two regions, and extrahepatic portal venous gas were each associated with ischaemia or poor outcome.<sup>10,39,48</sup>

#### Hepatic portal venous gas (strict definition) vs. pathologic PI

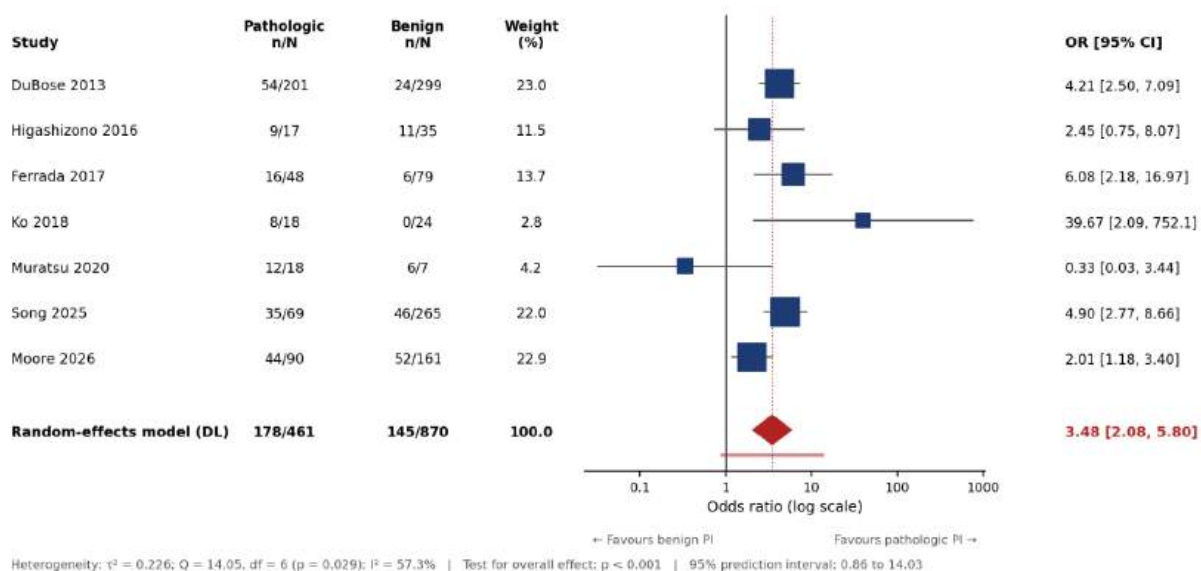


**Figure 5.** Forest plot of hepatic portal venous gas (strict definition) and pathologic PI.

#### Mesenteric (portomesenteric) venous gas vs. pathologic PI

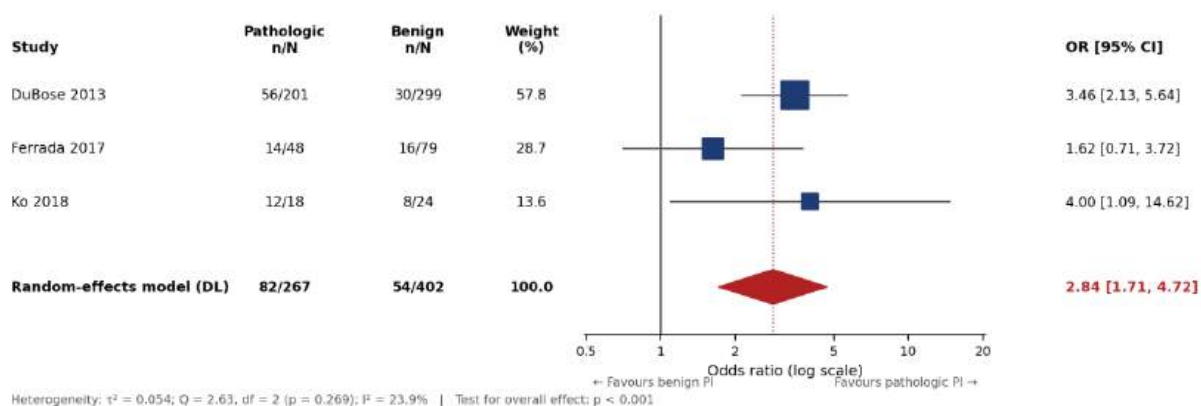


**Figure 6.** Forest plot of mesenteric (portomesenteric) venous gas and pathologic PI.

#### **Decreased or absent bowel wall enhancement**

Decreased or absent mural enhancement showed the largest pooled association with pathologic PI (OR 17.51, 95% CI 1.71–179.17; three studies; 174 patients), with substantial heterogeneity ( $I^2 = 79\%$ ;  $\tau^2 = 3.302$ ;  $p(Q) = 0.008$ ) that reflected differences in magnitude rather than direction. The largest effect was observed in the laparotomy subgroup of a study using blinded

double reading, in which 48 of 49 patients with surgically confirmed ischaemia had absent or doubtful enhancement and the rate of non-therapeutic laparotomy rose from 25% with absent enhancement to 94% with normal enhancement; in the full cohort, absent or doubtful enhancement remained the only independent CT predictor (adjusted OR 167.7, 95% CI 23.4–4,349.8).<sup>9</sup> Decreased enhancement was also significantly associated with ischaemia in a large emergency cohort (FDR-adjusted  $p < 0.001$ ), was an independent predictor of life-threatening PI in a Taiwanese cohort (adjusted OR 6.47), and predicted mortality in two further studies.<sup>10,16,40,46</sup>

Decreased/absent bowel wall enhancement vs. pathologic PI

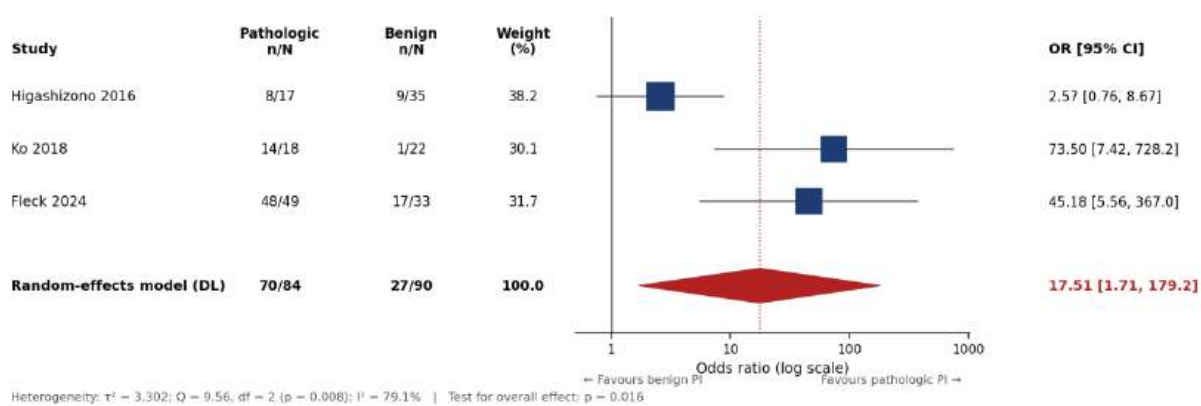


**Figure 7.** Forest plot of decreased/absent bowel wall enhancement and pathologic PI.

### **Mesenteric arterial or venous thrombosis/occlusion**

Mesenteric vascular occlusion was uncommon but highly specific. It was associated with a fivefold increase in the odds of pathologic PI (OR 5.26, 95% CI 2.07–13.36; three studies; 775 patients;  $I^2 = 0\%$ ;  $\tau^2 = 0.000$ ;  $p(Q) = 0.650$ ), with a pooled specificity of 98% but a sensitivity of only 8%. Arterial or venous thrombosis was also significantly associated with pathologic PI in an additional cohort of 313 patients that could not be pooled.<sup>6,7,10,17</sup>

#### Mesenteric arterial/venous thrombosis or occlusion vs. pathologic PI

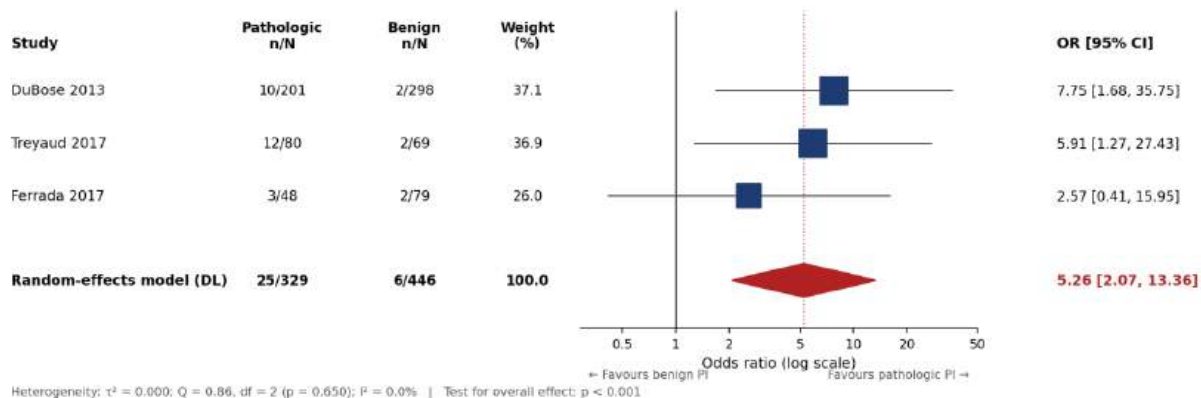


**Figure 8.** Forest plot of mesenteric arterial/venous thrombosis or occlusion and pathologic PI.

#### Ascites and free peritoneal fluid

Ascites was associated with pathologic PI in six studies (1080 patients) with no detectable heterogeneity (OR 2.77, 95% CI 2.09–3.67;  $I^2 = 0\%$ ;  $\tau^2 = 0.000$ ;  $p(Q) = 0.420$ ; 95% prediction interval 1.86–4.12). The direction of association was consistent in narrative studies, in which ascites or free fluid was associated with clinically worrisome PI, with bowel ischaemia, with the need for surgery and with mortality.<sup>6,11,13,15,38,42,47,49</sup>

#### Ascites / free peritoneal fluid vs. pathologic PI

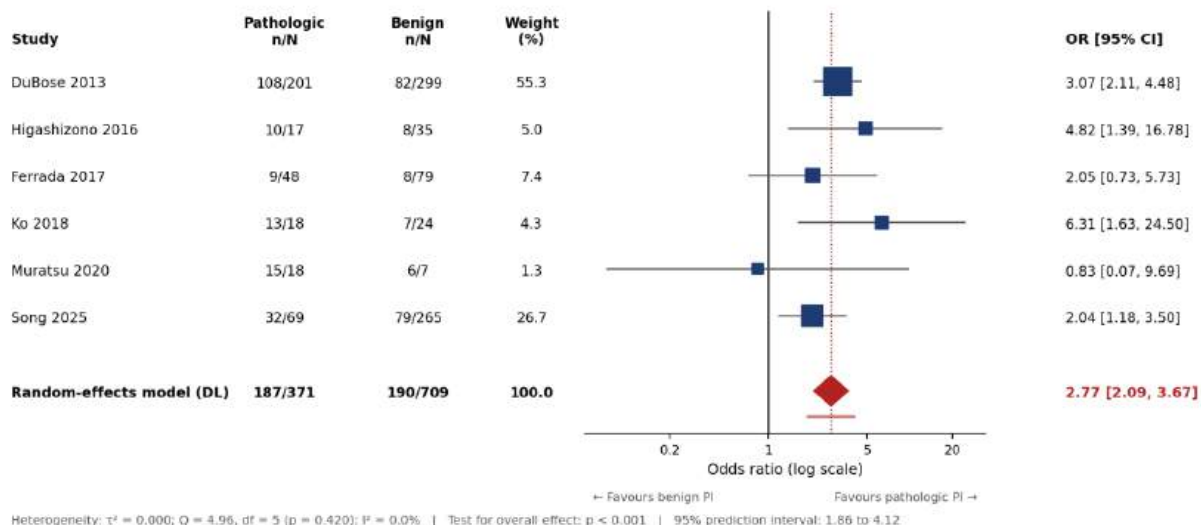


**Figure 9.** Forest plot of ascites/free peritoneal fluid and pathologic PI.

### Bowel dilatation and wall thickening

Bowel dilatation was not significantly associated with pathologic PI in pooled analysis (OR 2.05, 95% CI 0.69–6.09; three studies;  $I^2 = 84\%$ ;  $\tau^2 = 0.713$ ;  $p(Q) = 0.002$ ) (Figure 11): the effect was strong in a small cohort with clinically defined groups but null in the two large multicentre cohorts. Bowel wall thickening was likewise not associated (OR 1.25, 95% CI 0.93–1.68; three studies;  $I^2 = 0\%$ ;  $\tau^2 = 0.000$ ;  $p(Q) = 0.750$ ). In the narrative synthesis, dilatation was significantly associated with worrisome PI or adverse outcome in five of six additional reports, whereas wall thickening was associated in only one of two additional reports.<sup>6,7,11–13,15,37,40,43,44,49</sup>

**Bowel dilatation vs. pathologic PI**

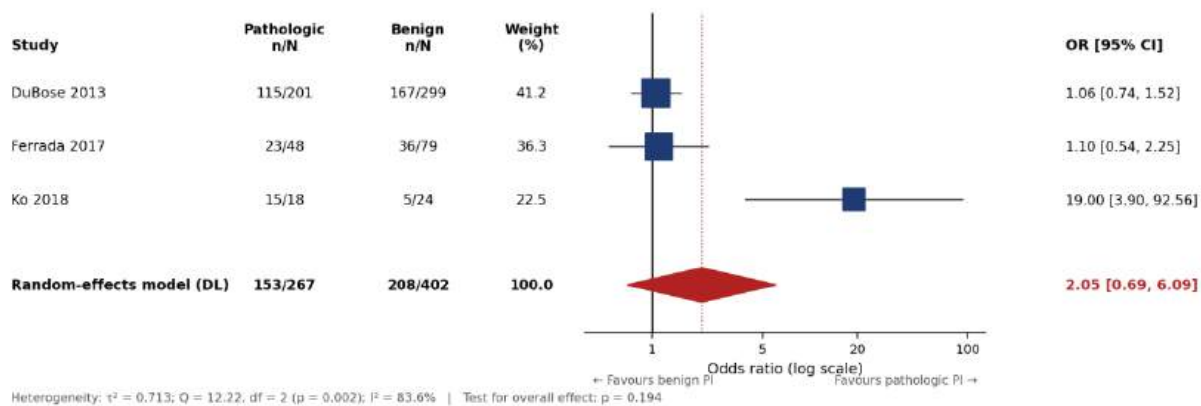


**Figure 10.** Forest plot of bowel dilatation and pathologic PI.

**Bowel wall thickening vs. pathologic PI**

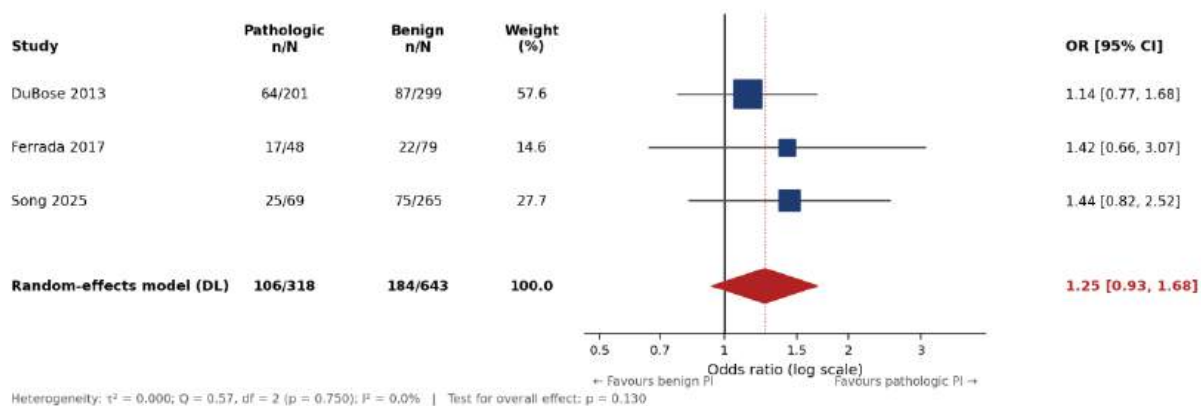


**Figure 11.** Forest plot of bowel wall thickening and pathologic PI.

### Location, extent and pattern of PI

Small-bowel involvement was associated with pathologic PI (OR 1.88, 95% CI 1.41–2.52; five studies; 1361 patients;  $I^2 = 31\%$ ;  $\tau^2 = 0.034$ ;  $p(Q) = 0.218$ ), and the association persisted when the ileal-only definition of one study was excluded (OR 1.60, 95% CI 1.19–2.15;  $I^2 = 0\%$ ). Colonic location was not associated with either pathologic or benign PI (OR 0.91, 95% CI 0.70–1.17; four studies;  $I^2 = 0\%$ ) (Figure 14). Small-bowel PI was also a component of a validated five-factor score and an independent predictor in a further study.<sup>6–8,10,14,15,17</sup>

Small-bowel location of PI vs. pathologic PI

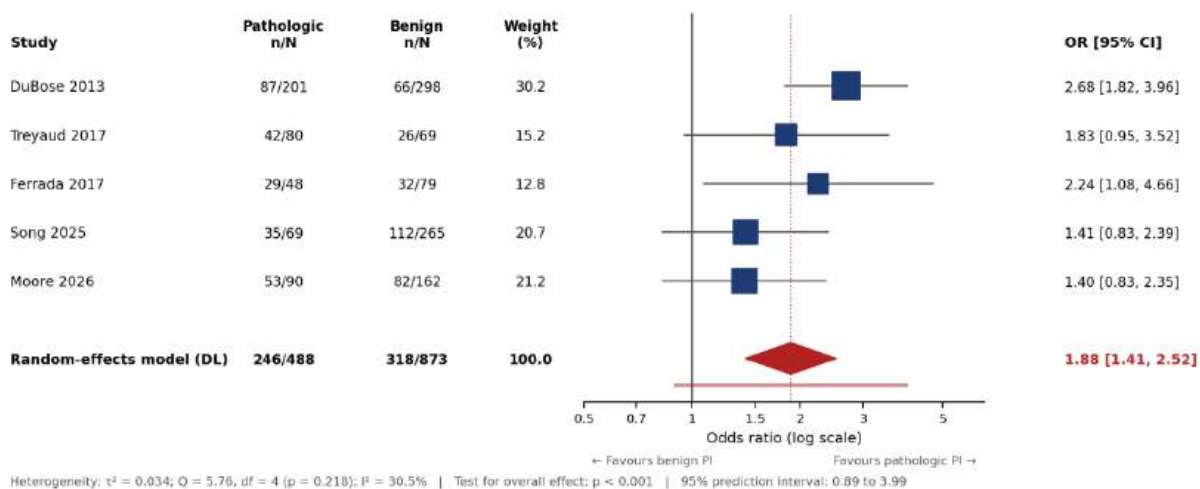


**Figure 12.** Forest plot of small-bowel location of PI and pathologic PI.

#### Colonic location of PI vs. pathologic PI

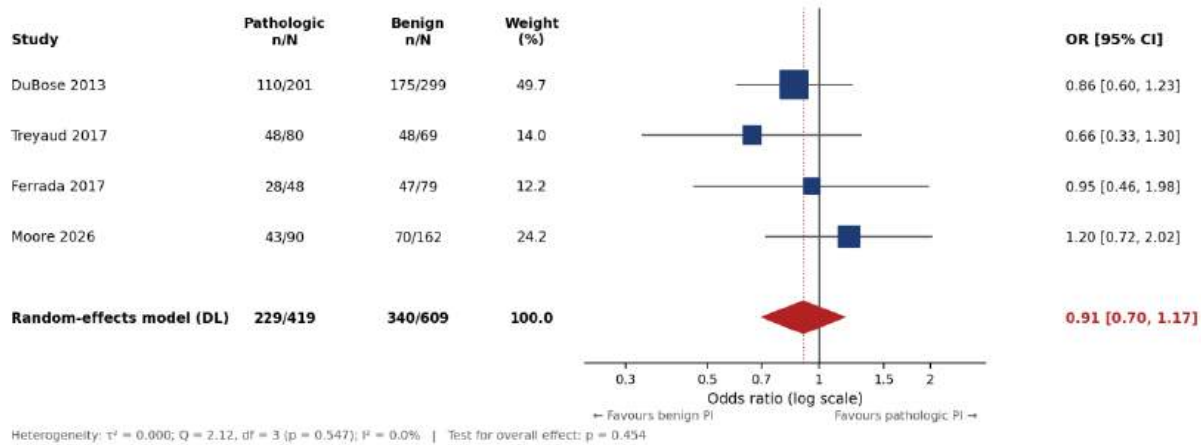


**Figure 13.** Forest plot of colonic location of PI and pathologic PI.

Multisegment or diffuse PI showed a non-significant trend towards pathologic PI (OR 1.68, 95% CI 0.94–3.00; three studies;  $I^2 = 71\%$ ;  $\tau^2 = 0.183$ ;  $p(Q) = 0.031$ ). Conversely, isolated foci of PI were associated with benign PI (OR 0.41, 95% CI 0.27–0.62; two studies;  $I^2 = 0\%$ ). The linear (band-like) pattern was not associated with pathologic PI (OR 1.12, 95% CI 0.32–3.87; two studies). In individual studies, mesenteric pneumatosis (adjusted OR 0.14) and circumferential "air-type" PI without wall oedema were associated with benign or non-necrotic PI.<sup>6,7,15,16,38,39</sup>

#### Multisegment/diffuse extent of PI vs. pathologic PI

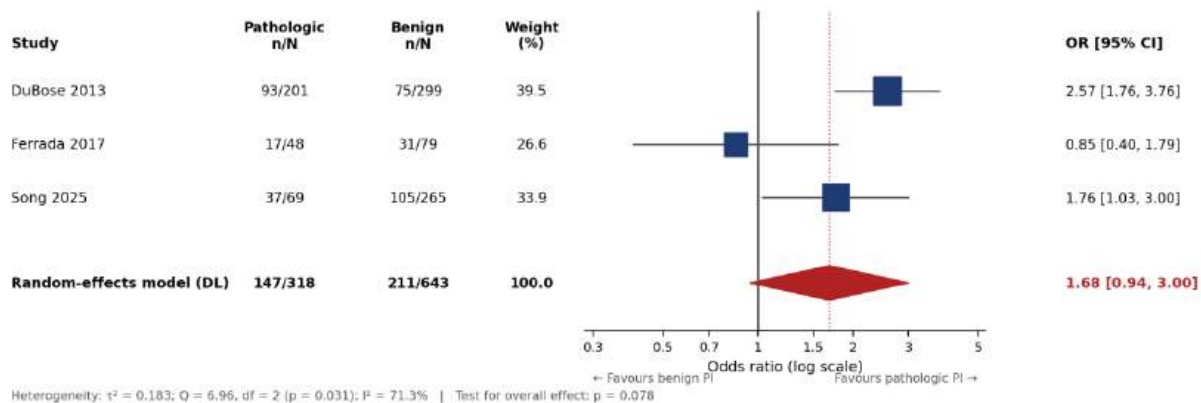


**Figure 14.** Forest plot of multisegment/diffuse extent of PI and pathologic PI.

#### Isolated foci of PI vs. pathologic PI

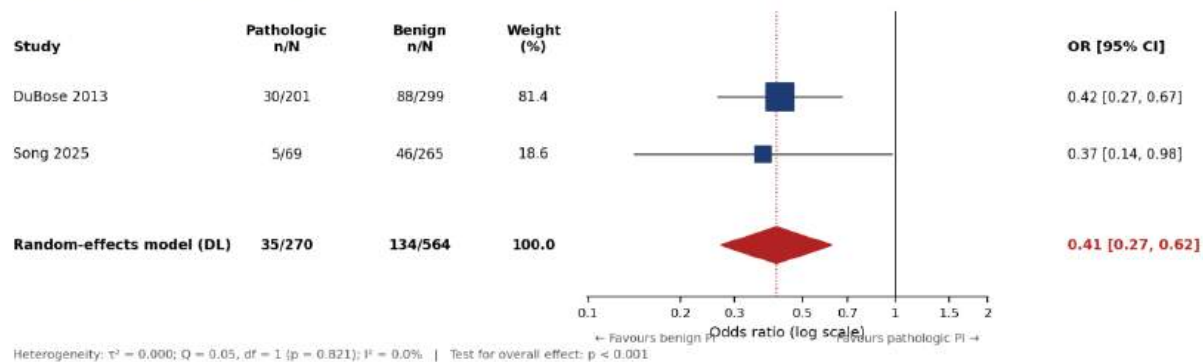


**Figure 15.** Forest plot of isolated foci of PI (a benign-pattern marker) and pathologic PI.

#### Linear (band-like) PI pattern vs. pathologic PI

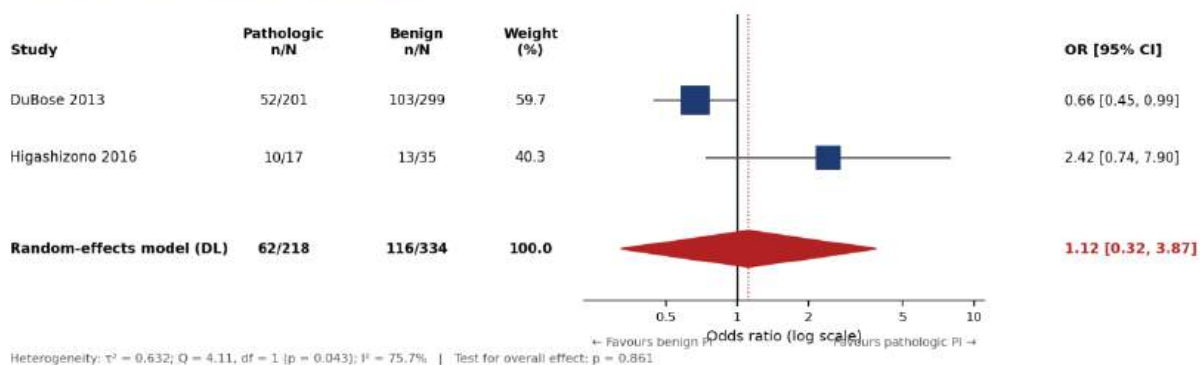


**Figure 16.** Forest plot of the linear (band-like) PI pattern and pathologic PI.

#### *Pneumoperitoneum and retroperitoneal air*

Pneumoperitoneum was not associated with pathologic PI (OR 1.02, 95% CI 0.64–1.63; seven studies; 1332 patients;  $I^2 = 51\%$ ;  $\tau^2 = 0.179$ ;  $p(Q) = 0.056$ ). Egger's test suggested small-study asymmetry ( $p = 0.033$ ), driven by one small cohort in which free air was significantly more frequent in non-necrotic cases; after its exclusion heterogeneity disappeared and the estimate remained null (OR 1.24, 95% CI 0.93–1.65;  $I^2 = 0\%$ ). Retroperitoneal air was also not associated (OR 0.74, 95% CI 0.36–1.51; two studies).<sup>6,13,39</sup>

#### Pneumoperitoneum (free intraperitoneal air) vs. pathologic PI

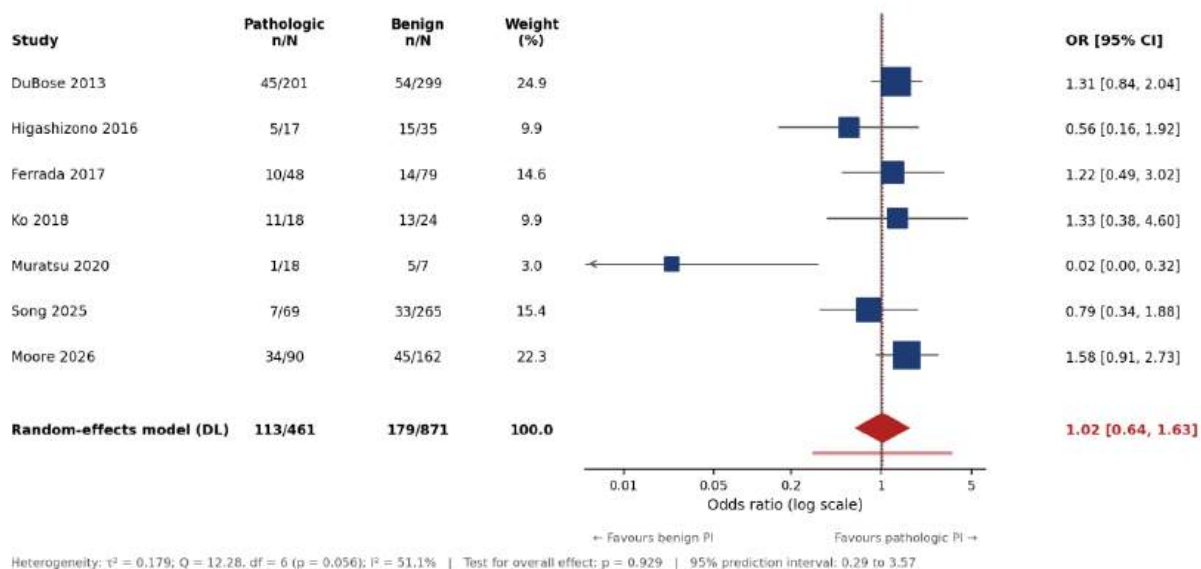


**Figure 17.** Forest plot of pneumoperitoneum (free intraperitoneal air) and pathologic PI.

#### Retroperitoneal air vs. pathologic PI

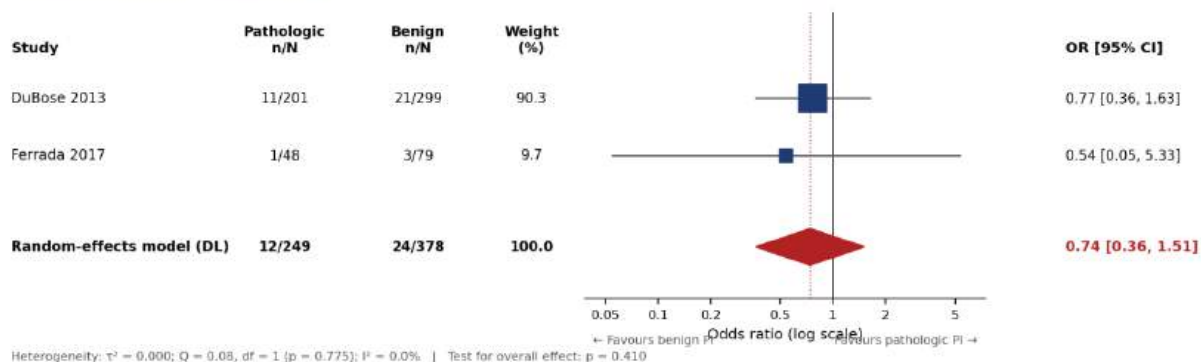


**Figure 18.** Forest plot of retroperitoneal air and pathologic PI.

#### Overview of pooled associations

Seven predictors were significantly associated with pathologic PI (decreased enhancement, vascular occlusion, hepatic portal venous gas, any PMVG, mesenteric venous gas, ascites and small-bowel location), one was associated with benign PI (isolated foci), and seven showed no significant association.

**Table 6.** Summary of meta-analyses of CT predictors of pathologic PI.

| CT predictor                             | k | N    | Random-effects OR (95% CI) | p      | Fixed-effect OR (95% CI) | HKSJ 95% CI  | I <sup>2</sup> ( % ) | τ <sup>2</sup> | 95% PI     | Egger p |
|------------------------------------------|---|------|----------------------------|--------|--------------------------|--------------|----------------------|----------------|------------|---------|
| Decreased/absent wall enhancement        | 3 | 174  | 17.51 (1.71–179.17)        | 0.016  | 8.37 (3.22–21.78)        | 0.17–1787.22 | 79                   | 3.302          | —          | —       |
| Mesenteric vascular thrombosis/occlusion | 3 | 775  | 5.26 (2.07–13.36)          | <0.001 | 5.26 (2.07–13.36)        | 1.37–20.14   | 0                    | 0.000          | —          | —       |
| Hepatic portal venous gas                | 7 | 1331 | 3.48 (2.08–5.80)           | <0.001 | 3.46 (2.60–4.60)         | 1.65–7.30    | 57                   | 0.226          | 0.86–14.03 | 0.966   |
| Portal/portomesenteric venous gas        | 8 | 1480 | 3.32 (2.23–4.96)           | <0.001 | 3.29 (2.56–4.23)         | 1.92–5.75    | 48                   | 0.135          | 1.19–9.30  | 0.911   |
| Mesenteric venous gas                    | 3 | 669  | 2.84 (1.71–4.72)           | <0.001 | 2.94 (1.97–4.39)         | 0.95–8.46    | 24                   | 0.054          | —          | —       |
| Ascites/free fluid                       | 6 | 1080 | 2.77 (2.09–3.67)           | <0.001 | 2.77 (2.09–3.67)         | 1.92–3.99    | 0                    | 0.000          | 1.86–4.12  | 0.974   |
| Bowel dilatation                         | 3 | 669  | 2.05 (0.69–6.09)           | 0.194  | 1.19 (0.87–1.64)         | 0.05–78.96   | 84                   | 0.713          | —          | —       |

|                             |   |          |                         |                |                         |                      |    |           |               |           |
|-----------------------------|---|----------|-------------------------|----------------|-------------------------|----------------------|----|-----------|---------------|-----------|
| Small-bowel location        | 5 | 13<br>61 | 1.88<br>(1.41–<br>2.52) | <0.<br>00<br>1 | 1.93<br>(1.52–<br>2.44) | 1.28–<br>2.78        | 31 | 0.0<br>34 | 0.89–<br>3.99 | 0.4<br>81 |
| Multisegment/diffuse extent | 3 | 96<br>1  | 1.68<br>(0.94–<br>3.00) | 0.0<br>78      | 1.96<br>(1.47–<br>2.61) | 0.44–<br>6.48        | 71 | 0.1<br>83 | —             | —         |
| Bowel wall thickening       | 3 | 96<br>1  | 1.25<br>(0.93–<br>1.68) | 0.1<br>30      | 1.25<br>(0.93–<br>1.68) | 0.89–<br>1.77        | 0  | 0.0<br>00 | —             | —         |
| Linear pattern              | 2 | 55<br>2  | 1.12<br>(0.32–<br>3.87) | 0.8<br>61      | 0.76<br>(0.52–<br>1.10) | 0.00–<br>3509.9<br>9 | 76 | 0.6<br>32 | —             | —         |
| Pneumoperitoneum            | 7 | 13<br>32 | 1.02<br>(0.64–<br>1.63) | 0.9<br>29      | 1.18<br>(0.89–<br>1.57) | 0.49–<br>2.12        | 51 | 0.1<br>79 | 0.29–<br>3.57 | 0.0<br>33 |
| Colonic location            | 4 | 10<br>28 | 0.91<br>(0.70–<br>1.17) | 0.4<br>54      | 0.91<br>(0.70–<br>1.17) | 0.64–<br>1.28        | 0  | 0.0<br>00 | —             | —         |
| Retroperitoneal air         | 2 | 62<br>7  | 0.74<br>(0.36–<br>1.51) | 0.4<br>10      | 0.74<br>(0.36–<br>1.51) | 0.20–<br>2.79        | 0  | 0.0<br>00 | —             | —         |
| Isolated foci of PI         | 2 | 83<br>4  | 0.41<br>(0.27–<br>0.62) | <0.<br>00<br>1 | 0.41<br>(0.27–<br>0.62) | 0.22–<br>0.76        | 0  | 0.0<br>00 | —             | —         |

*HKSJ, Hartung–Knapp–Sidik–Jonkman; PI, prediction interval (reported for  $k \geq 5$ ).*

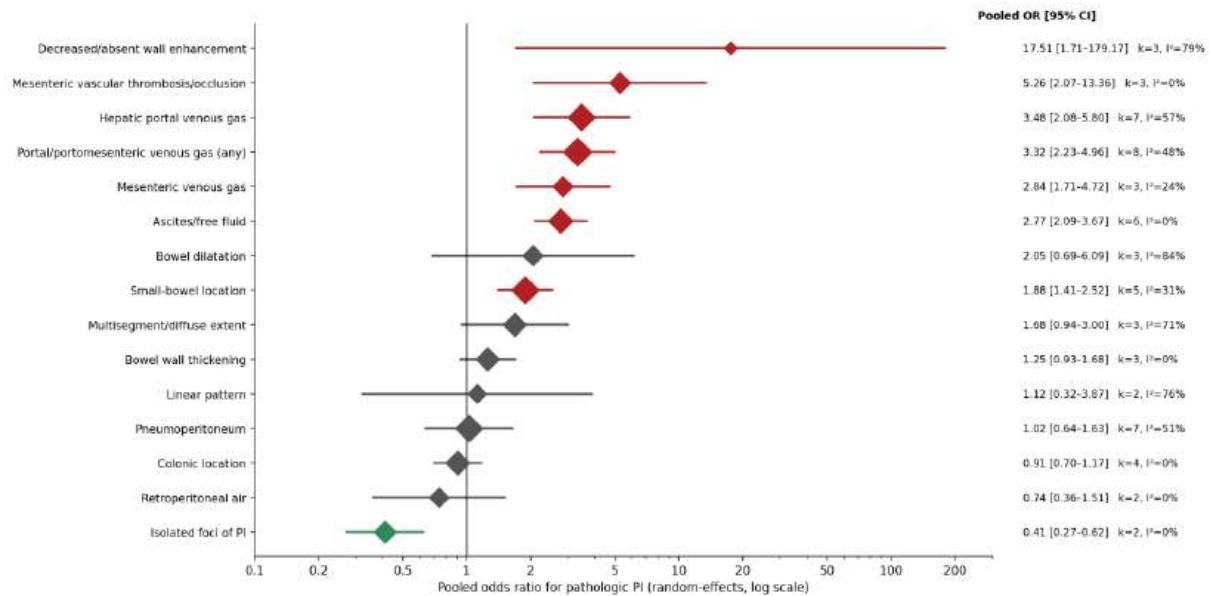


**Figure 19.** Summary forest plot of pooled odds ratios for all CT predictors (random-effects). Red, significant association with pathologic PI; green, significant association with benign PI; grey, non-significant. Marker size is proportional to the number of patients.

### Diagnostic performance of CT predictors

No single CT finding combined high sensitivity and high specificity. Findings related to vascular compromise and venous gas were specific but insensitive: PMVG had pooled sensitivity 45% (95% CI 39–51%) and specificity 80% (95% CI 70–87%) (LR+ 2.20; LR– 0.69), and vascular occlusion had a specificity of 98% (LR+ 4.76). Decreased enhancement provided the best overall balance (pooled sensitivity 82% (95% CI 40–97%) and specificity 74% (95% CI 44–91%); LR+ 3.14; LR– 0.25), although estimates were imprecise. Ascites had pooled sensitivity 53% (95% CI 38–68%) and specificity 74% (95% CI 65–81%).

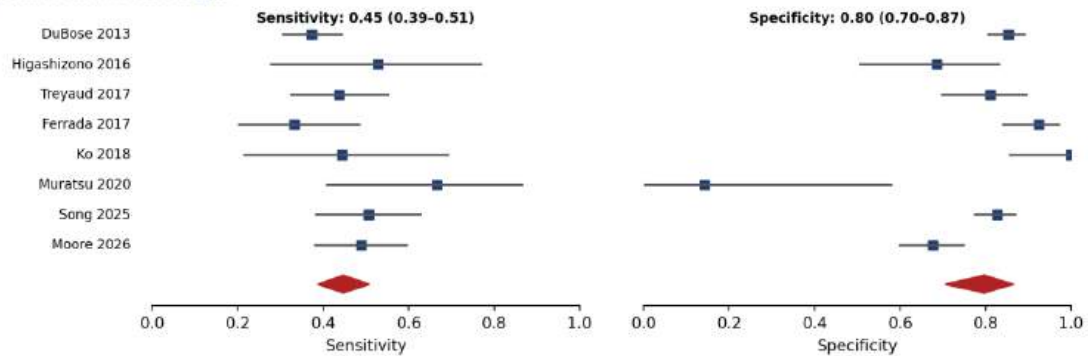
**Table 7.** Pooled diagnostic performance of CT findings for pathologic PI.

| CT predictor                      | k | Sensitivity, %<br>(95% CI) | Specificity, %<br>(95% CI) | LR+  | LR–  | DOR   |
|-----------------------------------|---|----------------------------|----------------------------|------|------|-------|
| Decreased/absent wall enhancement | 3 | 82 (40–97)                 | 74 (44–91)                 | 3.14 | 0.25 | 12.58 |

|                                          |   |            |            |      |      |      |
|------------------------------------------|---|------------|------------|------|------|------|
| Mesenteric vascular thrombosis/occlusion | 3 | 8 (4–17)   | 98 (96–99) | 4.76 | 0.94 | 5.09 |
| Hepatic portal venous gas                | 7 | 44 (33–56) | 81 (68–90) | 2.34 | 0.69 | 3.40 |
| Portal/portomesenteric venous gas        | 8 | 45 (39–51) | 80 (70–87) | 2.20 | 0.69 | 3.17 |
| Mesenteric venous gas                    | 3 | 38 (22–56) | 82 (66–91) | 2.03 | 0.77 | 2.65 |
| Ascites/free fluid                       | 6 | 53 (38–68) | 74 (65–81) | 2.07 | 0.63 | 3.27 |
| Bowel dilatation                         | 3 | 59 (44–72) | 56 (40–71) | 1.35 | 0.73 | 1.86 |
| Small-bowel location                     | 5 | 52 (45–59) | 62 (50–73) | 1.37 | 0.77 | 1.78 |
| Multisegment/diffuse extent              | 3 | 46 (38–54) | 66 (54–76) | 1.35 | 0.82 | 1.65 |
| Bowel wall thickening                    | 3 | 33 (28–39) | 71 (68–75) | 1.17 | 0.93 | 1.25 |
| Linear pattern                           | 2 | 40 (14–72) | 65 (60–70) | 1.14 | 0.93 | 1.23 |
| Pneumoperitoneum                         | 7 | 25 (16–38) | 72 (60–81) | 0.90 | 1.04 | 0.87 |
| Colonic location                         | 4 | 55 (50–59) | 43 (33–53) | 0.95 | 1.06 | 0.90 |
| Isolated foci of PI                      | 2 | 12 (6–22)  | 77 (63–87) | 0.50 | 1.15 | 0.44 |

*LR, likelihood ratio; DOR, diagnostic odds ratio derived from pooled sensitivity and specificity.*

**A. Portal/portomesenteric venous gas**



**B. Ascites/free fluid**

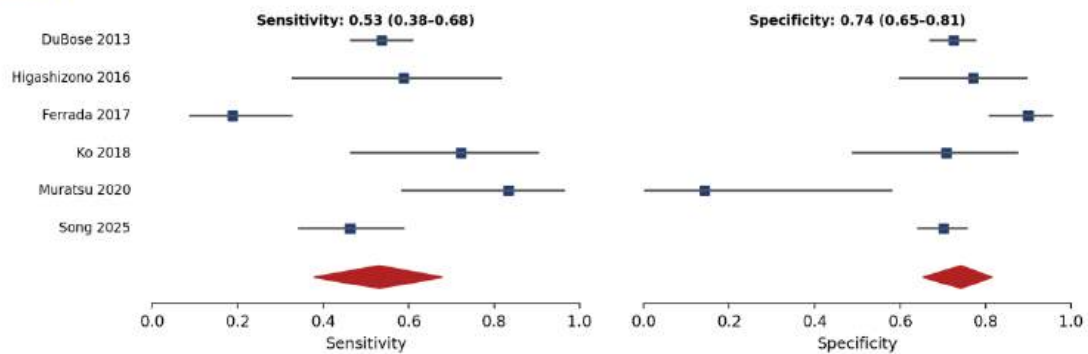


**Figure 20.** Paired forest plots of sensitivity and specificity for (A) portal/portomesenteric venous gas and (B) ascites. Exact 95% CIs for individual studies; diamonds indicate random-effects pooled estimates.

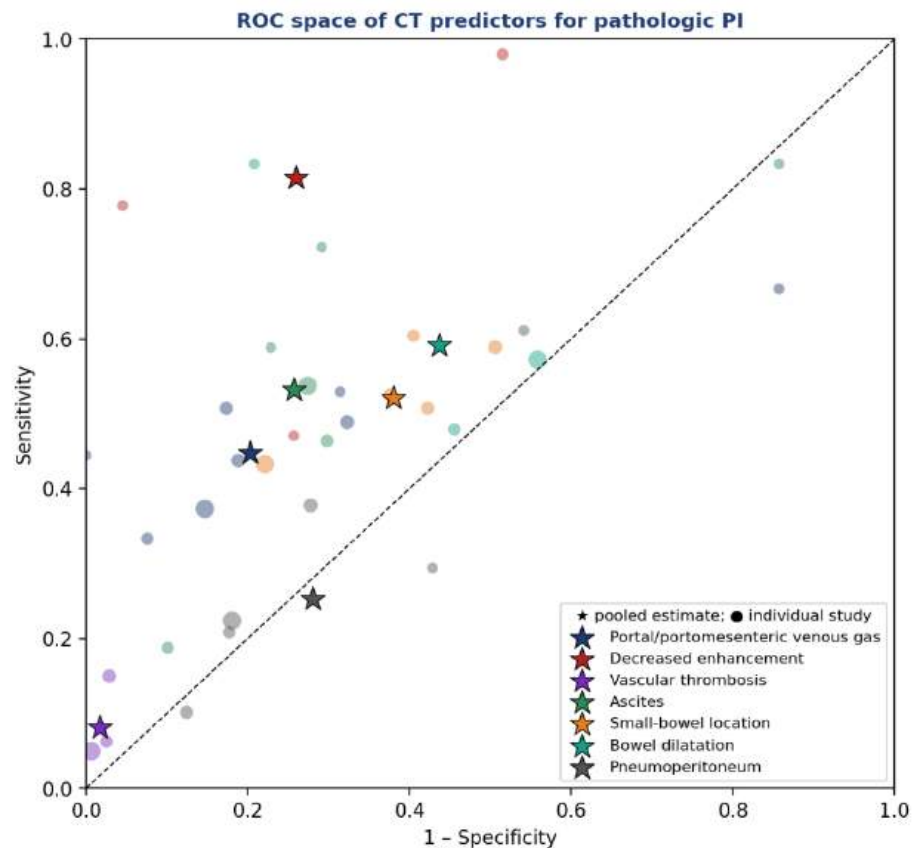


**Figure 21.** Receiver operating characteristic (ROC) space plot of individual-study (circles, size proportional to the number of pathologic cases) and pooled (stars) estimates for seven CT predictors.

### Subgroup and sensitivity analyses

For PMVG, none of the prespecified subgroup analyses demonstrated a significant difference between subgroups. The association was stronger in PI-only cohorts (OR 3.62, 95% CI 2.45–5.35) than in cohorts selected for PI and/or venous gas (OR 1.18, 95% CI 0.18–7.77;  $p$  for difference = 0.25), consistent with the expected attenuation when the exposure is part of the inclusion criterion. Estimates were similar in multicentre and single-centre studies and across regions and reference standards.

**Table 8.** Subgroup and sensitivity analyses.

| Analysis           | Stratum / scenario          | k | OR (95% CI)       | I <sup>2</sup> (%) | p (subgroup difference) |
|--------------------|-----------------------------|---|-------------------|--------------------|-------------------------|
| Population         | PI-only                     | 6 | 3.62 (2.45–5.35)  | 46                 | 0.25                    |
| Population         | PI and/or PVG               | 2 | 1.18 (0.18–7.77)  | 55                 | 0.25                    |
| Design             | Multicentre                 | 4 | 3.50 (2.26–5.43)  | 55                 | 0.71                    |
| Design             | Single-centre               | 4 | 2.78 (0.91–8.46)  | 54                 | 0.71                    |
| Region             | North America               | 4 | 3.50 (2.26–5.43)  | 55                 | 0.97                    |
| Region             | East Asia                   | 3 | 2.68 (0.32–22.73) | 68                 | 0.97                    |
| Region             | Europe                      | 1 | 3.35 (1.59–7.08)  | 0                  | 0.97                    |
| Reference standard | Composite (operative/death) | 2 | 3.92 (2.78–5.52)  | 0                  | 0.44                    |
| Reference standard | Operative/autopsy necrosis  | 4 | 2.40 (1.10–5.23)  | 53                 | 0.44                    |
| Reference standard | Clinical/aetiological       | 2 | 7.53 (0.78–73.07) | 61                 | 0.44                    |
| Sensitivity        | Main analysis (DL random-   | 8 | 3.32 (2.23–       | 48                 | —                       |

|                                |                                                   |   |                  |    |   |
|--------------------------------|---------------------------------------------------|---|------------------|----|---|
| (PMVG)                         | effects)                                          |   | 4.96)            |    |   |
| Sensitivity (PMVG)             | Excluding reconstructed data (Treyaud 2017)       | 7 | 3.32 (2.06–5.36) | 55 | — |
| Sensitivity (PMVG)             | Excluding PI and/or PVG cohorts                   | 6 | 3.62 (2.45–5.35) | 46 | — |
| Sensitivity (PMVG)             | Excluding high risk-of-bias studies (Ko, Muratsu) | 6 | 3.35 (2.45–4.59) | 28 | — |
| Sensitivity (PMVG)             | Strict hepatic portal venous gas only             | 7 | 3.48 (2.08–5.80) | 57 | — |
| Sensitivity (PMVG)             | Fixed-effect (inverse variance)                   | 8 | 3.29 (2.56–4.23) | 48 | — |
| Sensitivity (PMVG)             | Hartung-Knapp-Sidik-Jonkman                       | 8 | 3.32 (1.92–5.75) | 48 | — |
| Sensitivity (ascites)          | Main                                              | 6 | 2.77 (2.09–3.67) | 0  | — |
| Sensitivity (ascites)          | Excluding Muratsu (PI and/or PVG, n=25)           | 5 | 2.81 (2.12–3.74) | 1  | — |
| Sensitivity (ascites)          | Excluding high RoB (Ko, Muratsu)                  | 4 | 2.71 (2.04–3.62) | 0  | — |
| Sensitivity (small bowel)      | Main                                              | 5 | 1.88 (1.41–2.52) | 31 | — |
| Sensitivity (small bowel)      | Excluding DuBose (ileal-only definition)          | 4 | 1.60 (1.19–2.15) | 0  | — |
| Sensitivity (pneumoperitoneum) | Main                                              | 7 | 1.02 (0.64–1.63) | 51 | — |
| Sensitivity                    | Excluding Muratsu                                 | 6 | 1.24 (0.93–      | 0  | — |

|                    |  |  |       |  |  |
|--------------------|--|--|-------|--|--|
| (pneumoperitoneum) |  |  | 1.65) |  |  |
|--------------------|--|--|-------|--|--|

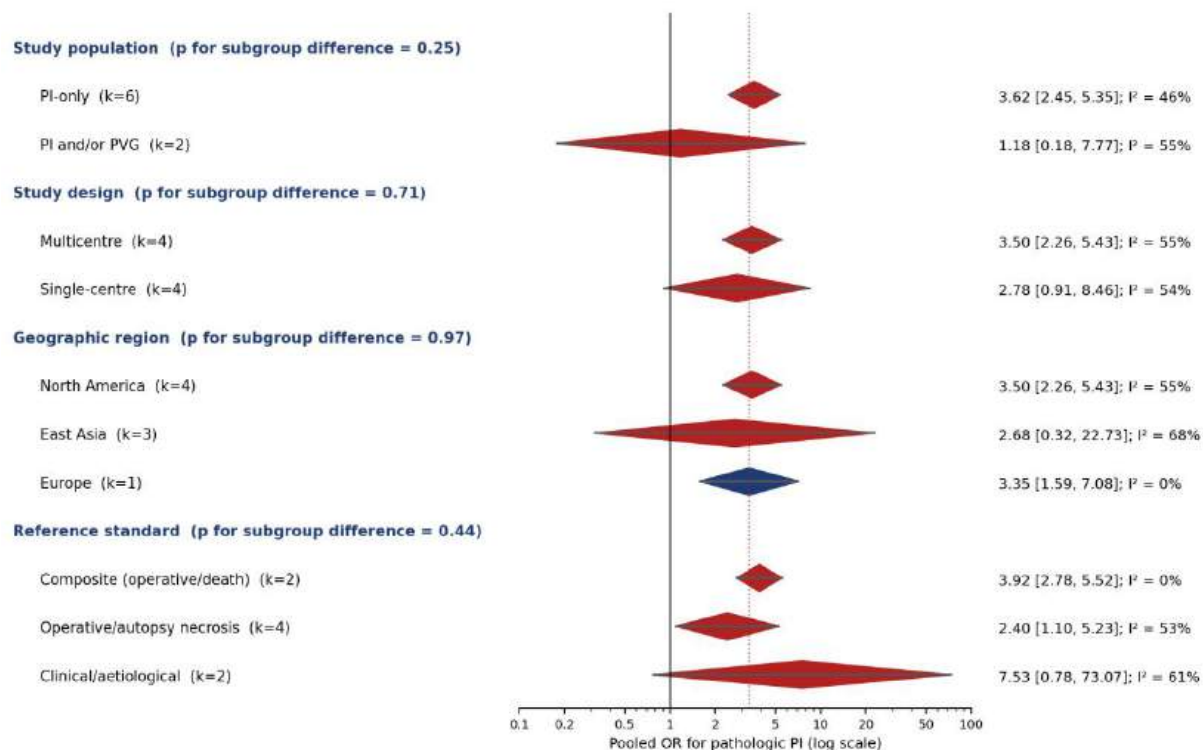


**Figure 22.** Subgroup analyses of the association between portal/portomesenteric venous gas and pathologic PI. Red diamonds indicate pooled subgroup estimates; navy diamond indicates a single study. Dotted line, overall pooled OR.

Leave-one-out analysis showed that no single study materially changed the pooled PMVG estimate (range of pooled OR 3.04–3.79; all lower confidence limits > 1.9), and cumulative meta-analysis showed that the association has been stable since the first large multicentre cohort in 2013. Exclusion of the reconstructed data, of high risk-of-bias studies and of PI and/or PVG cohorts, as well as fixed-effect and HKSJ modelling, all yielded concordant estimates. The ascites estimate was likewise robust (OR range 2.71–2.81).<sup>6</sup>

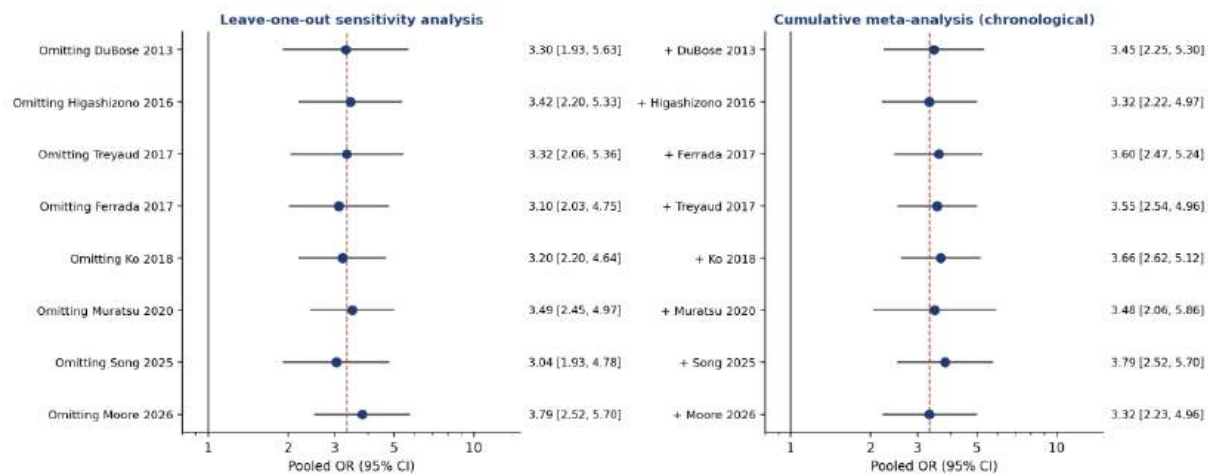


**Figure 23.** Leave-one-out (left) and cumulative (right, chronological) meta-analyses for portal/portomesenteric venous gas. Dashed red line, overall pooled OR.

### Small-study effects

There was no evidence of small-study effects for PMVG (Egger  $p = 0.91$ ; Begg  $p = 0.90$ ), hepatic portal venous gas (Egger  $p = 0.97$ ), ascites (Egger  $p = 0.97$ ) or small-bowel location (Egger  $p = 0.48$ ). Doi plots showed no asymmetry for PMVG (LFK index 0.54) and minor asymmetry for ascites (LFK index -1.06). The only signal of asymmetry concerned pneumoperitoneum, as described above.<sup>25,26</sup>

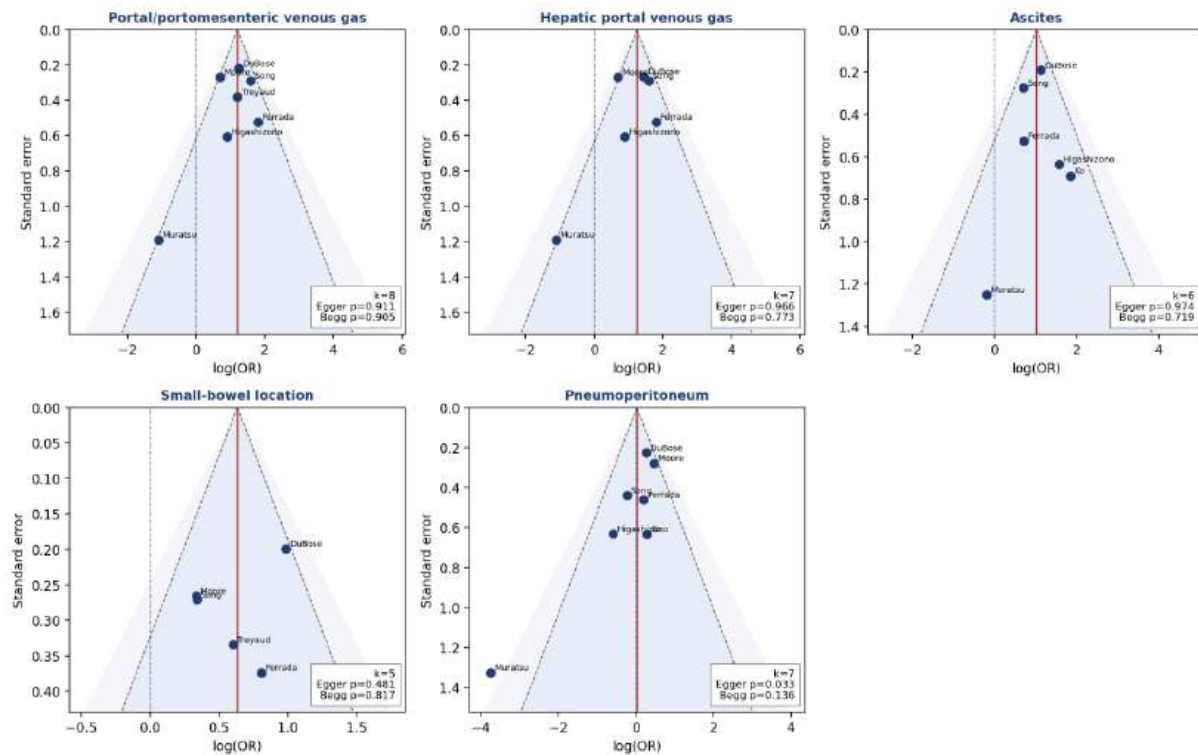


**Figure 24.** Contour-enhanced funnel plots (pseudo-95% and 99% confidence regions) for portal/portomesenteric venous gas, hepatic portal venous gas, ascites, small-bowel location and pneumoperitoneum, with Egger and Begg test p values.

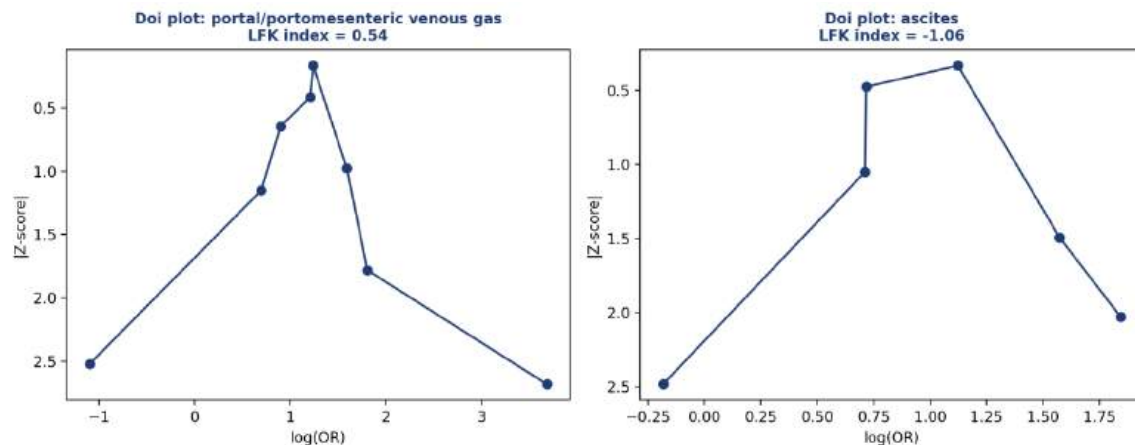


**Figure 25.** Doi plots with LFK indices for portal/portomesenteric venous gas and ascites.

**Narrative synthesis, including mesenteric fat stranding**

PMVG was significantly associated with pathologic PI or adverse outcome in 17 of 20 studies reporting it, and decreased enhancement in 8 of 10. Mesenteric fat stranding, which could not be pooled, was significantly associated with pathologic PI in 3 of 8 studies (cancer cohort, emergency radiology cohort and a large cohort of 313 patients), showed a non-significant trend in two, and was not associated in three, including two multicentre or emergency cohorts.<sup>10-12,17,40,43,48,49</sup> Benign-pattern markers (isolated or cystic foci, colon-confined PI, mesenteric pneumatosis and circumferential air-type PI) were associated with benign PI in all five studies that assessed them.<sup>6,11,15,16,39</sup>

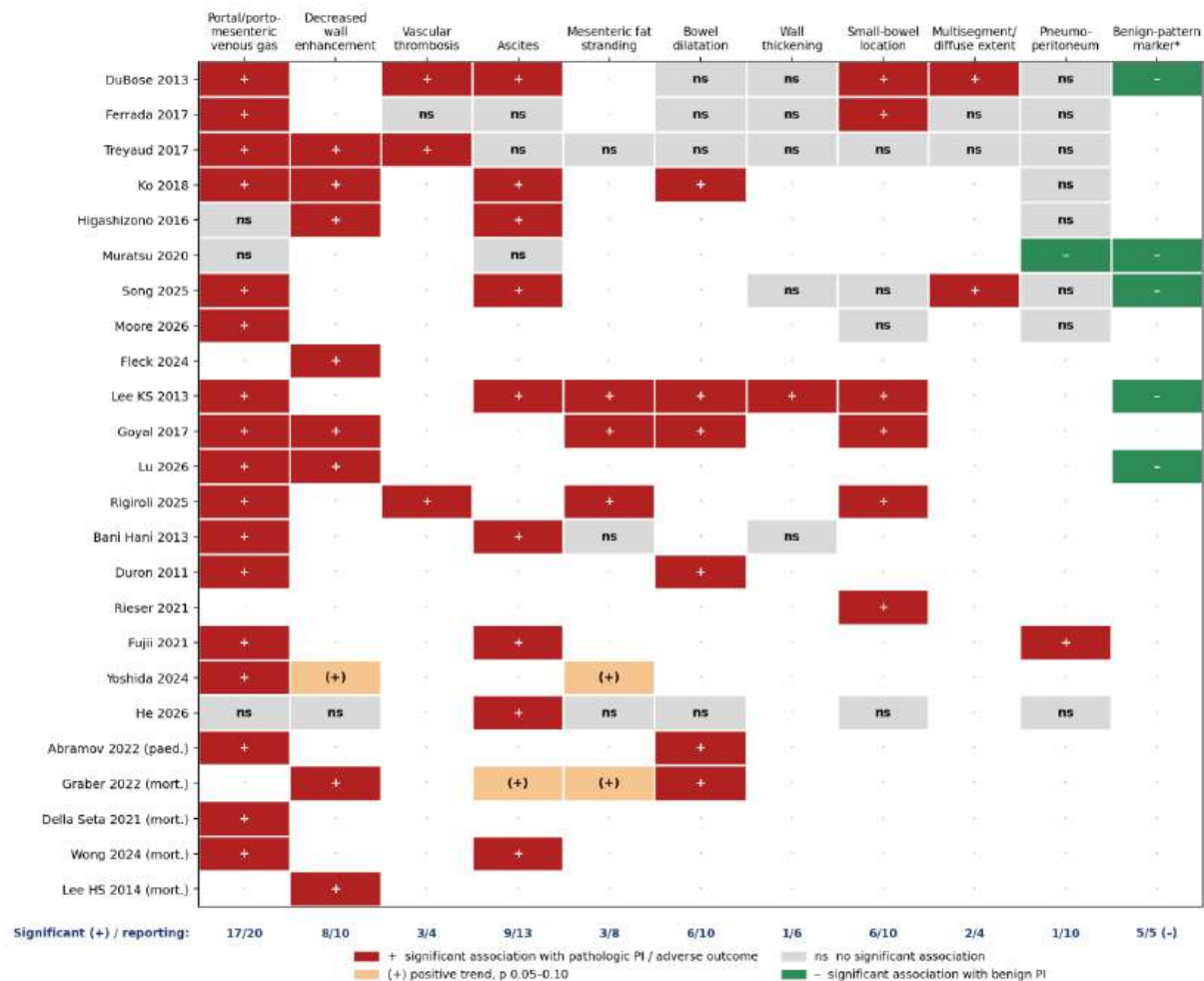


**Figure 26.** Harvest-style heat map of the direction and statistical significance of associations between CT features and pathologic PI or adverse outcome across 24 studies with feature-level data. \*Benign-pattern markers: isolated foci, colon-confined PI, mesenteric pneumatosis or circumferential air-type PI. paed., paediatric cohort; mort., mortality outcome.

In the paediatric cohort beyond the neonatal period, portal venous gas and bowel distension were significantly associated with pathologic PI, which occurred in only 7.2% of children.<sup>37</sup> In the oncology cohort, CT features rather than clinical factors (steroid use, chemotherapy) discriminated clinically worrisome PI.<sup>11</sup> Radiomic analysis of CT images alone achieved only modest discrimination (AUC 0.72), which increased to 0.91 when combined with clinical variables; a

clinical–radiological model similarly outperformed either component alone (AUC 0.85 versus 0.80).<sup>17,45</sup>

**Table 9.** Vote-counting synthesis of CT features across all studies with feature-level data (n = 24).

| CT feature                               | Studies reporting | Significant (pathologic/adverse) | Not significant | Significant (benign) | Comment                                                                                          |
|------------------------------------------|-------------------|----------------------------------|-----------------|----------------------|--------------------------------------------------------------------------------------------------|
| Portal/portomesenteric venous gas        | 20                | 17                               | 3               | 0                    | Consistent; attenuated in PI ± PVG cohorts; extrahepatic/segmental distribution most informative |
| Decreased/absent wall enhancement        | 10                | 8                                | 1 (trend 1)     | 0                    | Consistent; strongest magnitude; depends on contrast-enhanced, ideally biphasic CT               |
| Mesenteric vascular thrombosis/occlusion | 4                 | 3                                | 1               | 0                    | Highly specific; rare                                                                            |
| Ascites/free fluid                       | 13                | 9                                | 3 (trend 1)     | 0                    | Consistent; also predicts surgery and mortality                                                  |
| Mesenteric fat stranding                 | 8                 | 3                                | 3 (trend 2)     | 0                    | Inconsistent; not poolable; interobserver variability likely                                     |
| Bowel dilatation                         | 10                | 6                                | 4               | 0                    | Inconsistent in large multicentre cohorts                                                        |

|                             |    |   |   |   |                                                      |
|-----------------------------|----|---|---|---|------------------------------------------------------|
| Bowel wall thickening       | 6  | 1 | 5 | 0 | Mostly null                                          |
| Small-bowel location        | 10 | 6 | 4 | 0 | Moderately consistent                                |
| Multisegment/diffuse extent | 4  | 2 | 2 | 0 | Inconsistent                                         |
| Pneumoperitoneum            | 10 | 1 | 8 | 1 | Null overall; occasionally associated with benign PI |
| Benign-pattern markers*     | 5  | 0 | 0 | 5 | Consistently associated with benign PI               |

*\*Isolated or cystic foci, colon-confined PI, mesenteric pneumatosis, circumferential air-type PI.*

*Trend:  $0.05 \leq p < 0.10$ .*

### **Secondary outcome: CT findings and short-term mortality**

Two studies reported the association between venous gas and short-term mortality. In a three-centre German cohort, 90-day mortality increased from 46.5% with PI alone to 67.2% with concomitant PMVG, and in an Australian cohort concomitant PI and portal venous gas was associated with death (OR 8.25, 95% CI 3.04–22.38). The pooled estimate was 4.08 (95% CI 1.21–13.74) with high heterogeneity ( $I^2 = 79\%$ ).<sup>41,42</sup> In patients with clinically suspected mesenteric ischaemia, PI located in the colon, reduced colonic wall enhancement, colonic distension and perfusion inhomogeneities of solid abdominal organs were each associated with 30-day mortality, and colonic PI remained independently associated after adjustment (adjusted OR 2.86, 95% CI 1.08–8.04) (Figure 29).<sup>40</sup> Decreased or absent bowel wall enhancement combined with peritoneal irritation identified patients with a predicted in-hospital mortality of approximately 57–59%, compared with less than 5% when both were absent.<sup>46</sup>

#### PMVG/concomitant PVG and short-term mortality

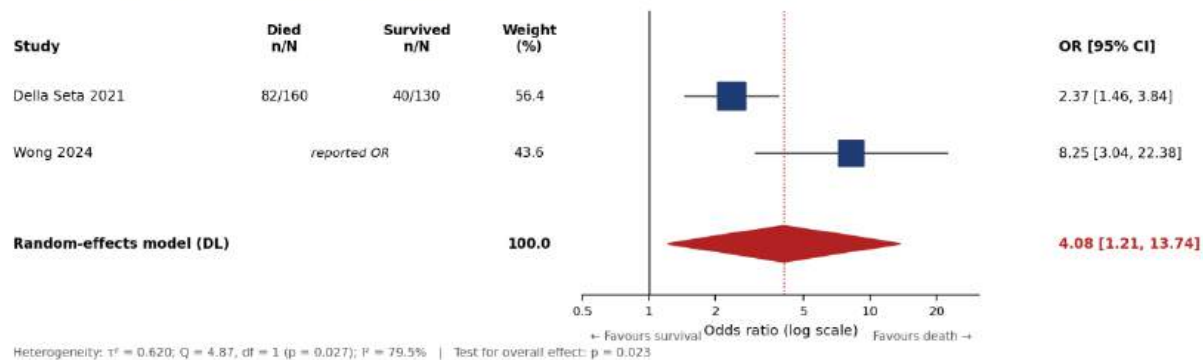


**Figure 27.** Forest plot of portomesenteric venous gas (or concomitant PI and portal venous gas) and short-term mortality.

#### Graber 2022: single-study estimates for 30-day mortality (not pooled)

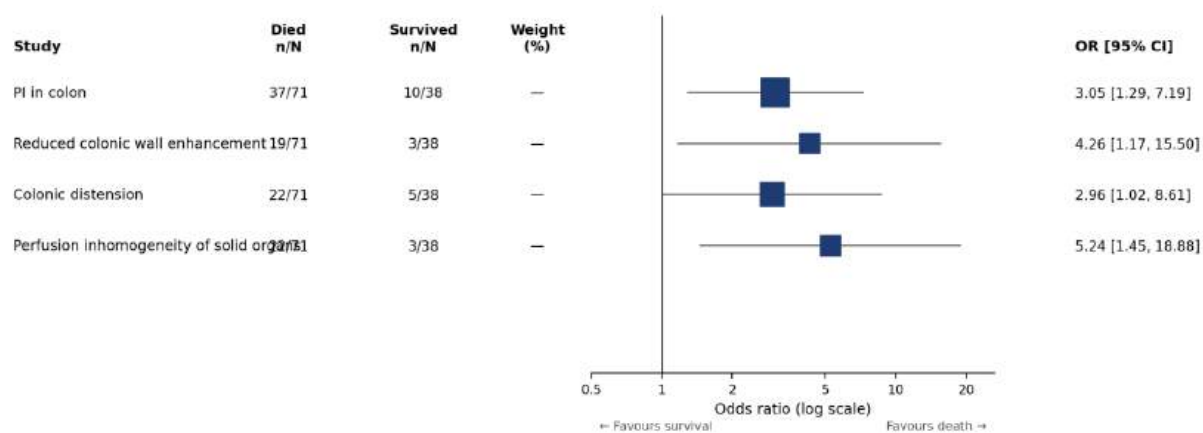


**Figure 28.** Single-study estimates (Graber et al.) of CT findings associated with 30-day mortality in patients with suspected mesenteric ischaemia and PI. Estimates derive from the same cohort and were not pooled.

#### Multivariable-adjusted estimates reported by primary studies

These were not pooled because covariate sets, model-building strategies and outcomes differed. In models that included clinical variables, the effect of individual CT findings was generally attenuated: in the largest surgical cohorts, peritonitis, hypotension or vasopressor requirement, lactate  $\geq 2$  mmol/L, end-organ dysfunction and leukocytosis dominated, and portal

venous gas retained independent significance in only some models. By contrast, in radiology-led cohorts in which bowel wall enhancement was assessed systematically, decreased enhancement and PMVG remained independent predictors.<sup>6,7,9,15,16,43</sup>

**Table 10.** Multivariable-adjusted or corrected associations of CT findings reported by primary studies (not pooled).

| Study          | CT finding                             | Outcome                     | Adjusted OR (95% CI) / result | Other variables in model                                          |
|----------------|----------------------------------------|-----------------------------|-------------------------------|-------------------------------------------------------------------|
| Fleck 2024     | Absent/doubtful bowel wall enhancement | Concomitant bowel ischaemia | 167.73 (23.39–4,349.81)       | Acute mesenteric ischaemia                                        |
| Lu 2026        | Portomesenteric venous gas             | Life-threatening PI         | 10.39 (CI NR; p < 0.001)      | ICU referral, enhancement, mesenteric pneumatosis                 |
| Lu 2026        | Decreased mural enhancement            | Life-threatening PI         | 6.47 (CI NR; p = 0.046)       | As above                                                          |
| Lu 2026        | Mesenteric pneumatosis                 | Life-threatening PI         | 0.14 (CI NR; p = 0.025)       | As above                                                          |
| Song 2025      | Portal venous gas                      | Pathologic PI               | 2.20 (1.02–4.78)              | Peritonitis, vasopressors, WBC, end-organ injury, multisegment PI |
| Song 2025      | Multisegment PI                        | Pathologic PI               | 1.91 (0.92–3.96)              | As above                                                          |
| Bani Hani 2013 | PI and PVG (vs either alone)           | Bowel ischaemia/necr        | 2.01 (0.94–4.36)              | Age ≥ 60, peritoneal signs,                                       |

|                 |                                   |                                                 |                                                                 |                                                   |
|-----------------|-----------------------------------|-------------------------------------------------|-----------------------------------------------------------------|---------------------------------------------------|
|                 |                                   | osis                                            |                                                                 | BUN > 25 mg/dL                                    |
| Wong<br>2024    | Concomitant PI<br>and PVG         | Mortality                                       | 8.25 (3.04–<br>22.38)                                           | Reported with<br>qSOFA, CCI,<br>lactate           |
| Wong<br>2024    | Free peritoneal<br>fluid          | Surgery                                         | 3.23 (1.44–7.28)                                                | —                                                 |
| He 2026         | Ascites                           | Surgical<br>treatment                           | 4.93 (1.04–<br>23.46)                                           | Red blood cell<br>count                           |
| Graber<br>2022  | PI in colon                       | 30-day<br>mortality                             | 2.86 (1.08–8.04)                                                | Surgery, AST,<br>solid-organ<br>perfusion         |
| Yoshida<br>2024 | Extrahepatic portal<br>venous gas | High-risk<br>group<br>(surgery/inoper-<br>able) | Only<br>independent<br>factor (p =<br>0.002)                    | Enhancement,<br>stranding, age,<br>renal disease  |
| Ferrada<br>2017 | Small-bowel PI,<br>ascites        | Pathologic PI                                   | Retained in final<br>model; not<br>independently<br>significant | Lactate, INR,<br>haemoglobin,<br>peritonitis, AKI |
| Treyaud<br>2017 | PMVG; decreased<br>enhancement    | Ischaemic<br>aetiology                          | FDR-adjusted p<br>= 0.009; p <<br>0.001                         | False discovery<br>rate correction                |

*AKI, acute kidney injury; AST, aspartate aminotransferase; BUN, blood urea nitrogen; CCI, Charlson Comorbidity Index; ICU, intensive care unit; INR, international normalised ratio; NR, not reported in the accessible report; qSOFA, quick Sequential Organ Failure Assessment; WBC, white blood cell count.*

### **Certainty of evidence**

Certainty of evidence was moderate for the associations of PMVG, hepatic portal venous gas, ascites and small-bowel location with pathologic PI, and for the absence of an association with colonic location. It was low for decreased bowel wall enhancement (rated down for risk of bias, inconsistency in magnitude and imprecision, and rated up for a large and directionally consistent effect), mesenteric vascular occlusion, mesenteric venous gas, isolated foci and the null associations of wall thickening and pneumoperitoneum, and very low for bowel dilatation, multisegment extent, mesenteric fat stranding and the PMVG–mortality association.<sup>19</sup>

**Table 11.** GRADE summary of findings for CT predictors of pathologic PI (prognostic-factor approach; evidence starts at high certainty).

| CT predictor                      | Studies (patients) | Pooled OR (95% CI)  | Risk of bias | Inconsistency | Imprecision | Indirectness | Publication bias | Upgrade         | Certainty         |
|-----------------------------------|--------------------|---------------------|--------------|---------------|-------------|--------------|------------------|-----------------|-------------------|
| Decreased/absent wall enhancement | 3 (174)            | 17.51 (1.71–179.17) | Serious      | Serious       | Serious     | Not serious  | Undetected       | +1 large effect | ⊕⊕○<br>○ Low      |
| Mesenteric vascular occlusion     | 3 (775)            | 5.26 (2.07–13.36)   | Serious      | Not serious   | Serious     | Not serious  | Undetected       | —               | ⊕⊕○<br>○ Low      |
| Portal/portomesenteric venous gas | 8 (1480)           | 3.32 (2.23–4.96)    | Serious      | Not serious   | Not serious | Not serious  | Undetected       | —               | ⊕⊕⊕<br>○ Moderate |
| Hepatic portal venous gas         | 7 (1331)           | 3.48 (2.08–         | Serious      | Not serious   | Not serious | Not serious  | Undetected       | —               | ⊕⊕⊕<br>○          |

|                                        |          |                  |         |             |             |             |            |   |                   |
|----------------------------------------|----------|------------------|---------|-------------|-------------|-------------|------------|---|-------------------|
|                                        | )        | 5.80)            |         | us          | us          | us          | ed         |   | Moderate          |
| Mesenteric venous gas                  | 3 (669)  | 2.84 (1.71–4.72) | Serious | Not serious | Serious     | Not serious | Undetected | — | ⊕⊕○<br>○ Low      |
| Ascites/free fluid                     | 6 (1080) | 2.77 (2.09–3.67) | Serious | Not serious | Not serious | Not serious | Undetected | — | ⊕⊕⊕<br>○ Moderate |
| Small-bowel location                   | 5 (1361) | 1.88 (1.41–2.52) | Serious | Not serious | Not serious | Not serious | Undetected | — | ⊕⊕⊕<br>○ Moderate |
| Isolated foci of PI (benign)           | 2 (834)  | 0.41 (0.27–0.62) | Serious | Not serious | Serious     | Not serious | Undetected | — | ⊕⊕○<br>○ Low      |
| Bowel dilatation                       | 3 (669)  | 2.05 (0.69–6.09) | Serious | Serious     | Serious     | Not serious | Undetected | — | ⊕○○<br>○ Very low |
| Multisegment/diffuse extent            | 3 (961)  | 1.68 (0.94–3.00) | Serious | Serious     | Serious     | Not serious | Undetected | — | ⊕○○<br>○ Very low |
| Bowel wall thickening (no association) | 3 (961)  | 1.25 (0.93–1.68) | Serious | Not serious | Serious     | Not serious | Undetected | — | ⊕⊕○<br>○ Low      |
| Pneumoperitoneum (no                   | 7 (1332) | 1.02 (0.64–      | Serious | Serious     | Not serious | Not serious | Suspected  | — | ⊕○○<br>○ Very     |

|                                      |               |                            |         |             |             |             |               |   |                      |
|--------------------------------------|---------------|----------------------------|---------|-------------|-------------|-------------|---------------|---|----------------------|
| association)                         | )             | 1.63)                      |         |             | us          | us          | d*            |   | low                  |
| Colonic location (no association)    | 4 (1028)      | 0.91 (0.70–1.17)           | Serious | Not serious | Not serious | Not serious | Undetected    | — | ⊕⊕⊕<br>○<br>Moderate |
| Mesenteric fat stranding (narrative) | 8 (narrative) | Significant in 3/8 studies | Serious | Serious     | Serious     | Not serious | Cannot assess | — | ⊕○○<br>○ Very low    |
| PMVG and short-term mortality        | 2 (290)       | 4.08 (1.21–13.74)          | Serious | Serious     | Serious     | Not serious | Cannot assess | — | ⊕○○<br>○ Very low    |

\*Egger  $p = 0.033$ , driven by one small study. Ratings for null associations refer to certainty that no clinically important association exists.

## DISCUSSION

### Principal findings

This systematic review and meta-analysis of 25 cohort studies, 12 of which provided poolable data, shows that the CT features that most strongly discriminate pathologic from benign PI are those reflecting compromised mural perfusion—decreased or absent bowel wall enhancement (OR 17.51, 95% CI 1.71–179.17) and mesenteric arterial or venous occlusion (OR 5.26, 95% CI 2.07–13.36)—followed by portal or portomesenteric venous gas (OR 3.32, 95% CI 2.23–4.96), ascites (OR 2.77, 95% CI 2.09–3.67) and small-bowel location (OR 1.88, 95% CI 1.41–2.52). Isolated foci of PI pointed towards benign disease, whereas pneumoperitoneum, wall thickening, colonic location, bowel dilatation and multisegment extent did not reliably discriminate. These results support our primary hypothesis regarding perfusion-related and venous gas findings, and the null hypothesis could be rejected for eight features (seven positively and one inversely associated

with pathologic PI). The hypothesis regarding mesenteric fat stranding was only partially supported, because its association was inconsistent and could not be quantified.

An equally important message concerns diagnostic performance. No CT feature was simultaneously sensitive and specific. PMVG and vascular occlusion were specific (80% and 98%) but missed the majority of pathologic cases, so that their absence cannot be used to exclude ischaemia. Decreased enhancement offered the best balance, with a pooled negative likelihood ratio of approximately 0.25, but its estimates were imprecise and depended on contrast-enhanced imaging. These findings explain why the large surgical cohorts consistently found that clinical and laboratory variables outperformed isolated imaging signs, and why combined clinical–radiological models achieved the best discrimination.<sup>6,7,15,17,45</sup>

### **Perfusion-related signs: bowel wall enhancement and vascular occlusion**

The magnitude of association for decreased or absent enhancement is biologically plausible. Mural hypoenhancement is the direct imaging correlate of reduced capillary perfusion and precedes transmural necrosis; in acute mesenteric ischaemia it is regarded as one of the most specific CT signs, particularly when assessed on biphasic or multiphasic CT with optimised iodine conspicuity. In the present review the strongest evidence came from a cohort with blinded double reading, in which normal enhancement was associated with a 94% rate of non-therapeutic laparotomy, implying that the presence of preserved enhancement should strongly temper the decision to operate on the basis of PI alone.<sup>9,18</sup>

The heterogeneity observed for this predictor ( $I^2$  79%) was one of magnitude rather than direction and is explained by differences in contrast protocols (up to one-third of patients in one emergency cohort underwent non-enhanced CT only), by the subjective nature of enhancement assessment, and by the selection of a laparotomy subgroup in one study. Mesenteric vascular occlusion, although uncommon (sensitivity 8%), was nearly pathognomonic for pathologic PI. Its rarity should not lead to its neglect: systematic evaluation of the superior mesenteric artery and vein, the inferior mesenteric artery and signs of non-occlusive mesenteric ischaemia (diffuse arterial narrowing, solid-organ perfusion defects) is indispensable whenever PI is detected.<sup>6,10,17,40</sup>

### **Portal and portomesenteric venous gas**

Venous gas has traditionally been regarded as an ominous sign, with historically reported mortality rates of 65–86% when it accompanies PI.<sup>13</sup> Our pooled estimate confirms a robust but moderate association that remained stable across eight studies, subgroups, leave-one-out and cumulative analyses and was not driven by small-study effects. The modest sensitivity (45%) indicates that most patients with pathologic PI do not have visible venous gas, and the specificity of 80% indicates that one in five patients with benign PI does. Venous gas may arise from benign processes such as mechanical bowel distension, endoscopy, gastric dilatation, obstruction or haemodialysis-related events, which explains its occurrence in a substantial fraction of patients who recover with conservative treatment.<sup>8,10,15,36,49</sup>

Several primary studies suggest that the distribution and quantity of venous gas refine its significance. Gas in segmental mesenteric veins and the extrahepatic portal vein, gas involving multiple regions or three or more hepatic segments, and extrahepatic portal venous gas were each more strongly associated with ischaemia, necrosis or mortality than intrahepatic gas alone. These observations support reporting the anatomical extent of venous gas rather than merely its presence. The weaker association observed in cohorts selected for PI and/or venous gas is expected, because conditioning inclusion on the exposure restricts its variability and attenuates measures of association.<sup>10,34,38,39,48</sup>

### **Ascites, mesenteric fat stranding and bowel calibre**

Ascites was the most consistent ancillary finding, with no detectable heterogeneity across six studies and consistent direction in narrative reports, including its association with the need for surgery and with mortality. Free fluid in ischaemic bowel results from increased capillary permeability, transudation and, in later stages, peritoneal inflammation, and it is easily and reproducibly detected on CT. Its specificity is limited, however, because ascites is common in critically ill, cirrhotic and oncological patients.<sup>6,15,42,47,49</sup>

Mesenteric fat stranding was significantly associated with pathologic PI in three studies, including a cancer cohort and a large single-institution cohort that incorporated stranding into a combined model, but not in an emergency cohort or a multicentre cohort. This inconsistency probably reflects variable definitions (stranding versus mesenteric oedema), interobserver

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variability and confounding by inflammatory and infectious causes of PI. Similarly, bowel dilatation was associated with pathologic PI in smaller radiology-led and paediatric cohorts but not in the two large multicentre surgical cohorts, in which dilatation was frequent in both groups because obstruction and ileus are common causes of benign PI. Bowel wall thickening was largely non-discriminatory, consistent with its occurrence in both ischaemic and inflammatory or infectious enterocolitis.<sup>6,7,10–13,17,37,43</sup>

### **Location, extent and morphology of intramural gas**

Small-bowel involvement was associated with pathologic PI, whereas colonic location was neutral. Colonic PI frequently reflects benign mechanisms—pneumatosis cystoides, drug-induced PI, chronic obstructive pulmonary disease or post-endoscopic gas—whereas the small bowel is the principal target of occlusive and non-occlusive mesenteric ischaemia and has a thinner wall with lower tolerance of ischaemia. Nevertheless, colonic PI was associated with mortality among patients with suspected mesenteric ischaemia, illustrating that location must be interpreted in clinical context.<sup>5–7,14,40</sup>

The morphology of intramural gas has long been debated. Our pooled analysis did not confirm the traditional teaching that a linear or band-like pattern indicates ischaemia, whereas isolated foci of gas were associated with benign PI. Two recent observations deserve emphasis: mesenteric pneumatosis (gas tracking into the mesentery) was an independent predictor of benign PI, and circumferential "air-type" PI without wall oedema was observed only in non-necrotic cases. These findings are consistent with the concept that gas dissecting along tissue planes under pressure, without mural injury, produces voluminous but benign pneumatosis, whereas ischaemic PI tends to be associated with a damaged, oedematous or hypoenhancing wall.<sup>6,15,16,39</sup>

### **Pneumoperitoneum**

Pneumoperitoneum is frequently regarded as an indication for laparotomy. In patients with PI, however, free air was not associated with pathologic PI in seven studies and was even more frequent among non-necrotic cases in one cohort, although another small cohort reported the opposite direction.<sup>47</sup> Rupture of subserosal gas cysts is a well-recognised benign source of free air ("balanced" or "benign" pneumoperitoneum), and the absence of a visible wall defect, of

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extraluminal fluid or contrast and of peritonitis should prompt consideration of this mechanism before surgical exploration. This finding has direct implications for avoiding non-therapeutic laparotomies.<sup>8,13,15,39,49</sup>

### **Integration with clinical and laboratory predictors**

The CT findings identified here should be interpreted within the clinical context. In the multicentre PIPES cohorts, lactate  $\geq 2$  mmol/L, peritonitis, hypotension or vasopressor use, acute kidney injury, mechanical ventilation and absent bowel sounds were the dominant independent predictors, and combined clinical decision rules achieved a predictive probability exceeding 90% when lactate elevation coexisted with haemodynamic instability. A five-factor score including small-bowel PI, age, tachycardia, lactate and the neutrophil–lymphocyte ratio achieved excellent discrimination in its derivation and validation cohorts, but performed poorly in external validation, underscoring the risk of overfitting and the need for broader validation.<sup>6–8,14</sup> A nomogram including portal venous gas, multisegment PI, vasopressor use, peritonitis, leukocytosis and end-organ injury, and a combined clinical–radiological model including porto-mesenteric gas and fat stranding (AUC 0.85), illustrate the incremental value of CT features over clinical data alone. Radiomic features alone provided only modest discrimination, but improved prediction when combined with clinical variables.<sup>15,17,45</sup>

### **Comparison with previous systematic reviews**

In patients with established acute mesenteric ischaemia, bowel wall thinning, decreased enhancement, bowel dilatation, PI and PMVG were all predictors of transmural necrosis, with diagnostic odds ratios between approximately 3 and 13. Our estimates for decreased enhancement and venous gas are directionally concordant, but our review addresses the complementary and clinically more frequent question of how to interpret ancillary findings once PI has been detected, including in patients without suspected ischaemia. A systematic review of anticancer-treatment-related PI showed that most drug-related cases were colonic, mild and managed conservatively, but that a minority were fatal, which aligns with our findings that colonic location is neutral and that oncological PI should be interpreted according to accompanying CT signs.<sup>5,11,18</sup>

**Table 12.** Comparison of the present review with previous systematic reviews.

| Review                          | Population                                                                     | Outcome                             | Main findings                                                                                                                                                                                     | Comment                                                                                                   |
|---------------------------------|--------------------------------------------------------------------------------|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Zeng et al. 2023 (Eur Radiol)   | Acute mesenteric ischaemia (11 studies; 1,037 patients)                        | Transmural intestinal necrosis      | Bowel wall thinning DOR 13.10; decreased enhancement DOR 5.77; PI DOR 5.78; PMVG DOR 5.36; dilatation DOR 3.23; arterial occlusive AMI DOR 2.66                                                   | PI treated as an exposure; population restricted to AMI                                                   |
| Gazzaniga et al. 2022 (Cancers) | Cancer patients with anticancer-treatment-related PI (62 papers; 88 episodes)  | Clinical course and outcome         | Mostly targeted therapy, large-bowel location, within 12 weeks; fatal in 11 episodes                                                                                                              | Case-level data; no CT predictor analysis                                                                 |
| Present review                  | Patients with CT-detected PI (25 studies; 4,392 patients; 12 in meta-analysis) | Pathologic PI; short-term mortality | Decreased enhancement OR 17.5; vascular occlusion OR 5.3; PMVG OR 3.3; ascites OR 2.8; small bowel OR 1.9; isolated foci OR 0.41; pneumoperitoneum, thickening, colon, dilatation: no association | First pooled analysis in the PI population; diagnostic accuracy, subgroup, sensitivity and GRADE analyses |

### Special populations

Children beyond the neonatal period represent a distinct population in which PI is predominantly benign (pathologic PI in 7.2%) and frequently associated with developmental delay, oncological treatment and transplantation; portal venous gas and bowel distension were nevertheless associated with pathologic disease. In patients with cancer, steroids and chemotherapy were not discriminatory, whereas CT features were, and benign colon-confined PI predominated. In mechanical small-bowel obstruction, PI and portal venous gas may occur with viable bowel and should not by themselves prompt resection. Postoperative PI or venous gas, by contrast, was strongly associated with bowel necrosis, implying a lower threshold for re-exploration after abdominal surgery.<sup>11,36–38</sup>

### **Clinical implications, structured reporting and a proposed pathway**

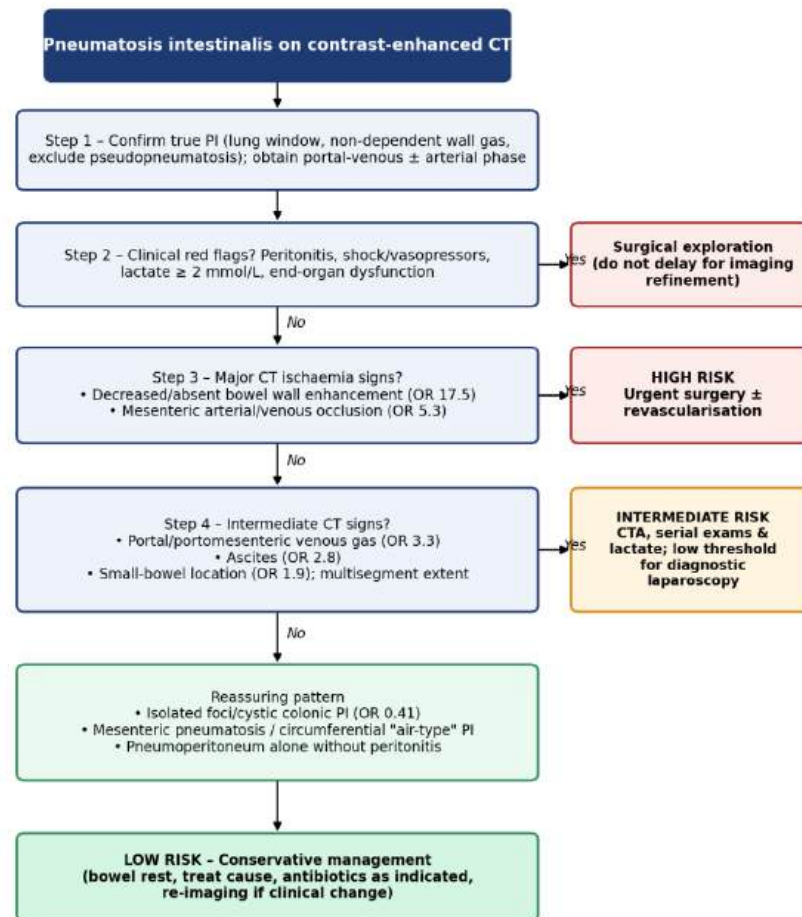
Based on the pooled estimates, we propose a structured CT report for PI (Table 14) and an evidence-informed appraisal pathway. The first step is to confirm true PI and to exclude pseudopneumatosis. Clinical red flags (peritonitis, shock or vasopressor requirement, lactate  $\geq 2$  mmol/L, end-organ dysfunction) should prompt surgical exploration irrespective of imaging subtleties. In the absence of red flags, decreased or absent enhancement and mesenteric vascular occlusion define a high-risk category; PMVG (particularly extrahepatic or mesenteric), ascites, small-bowel location and multisegment involvement define an intermediate-risk category warranting CT angiography, serial clinical and lactate assessment and a low threshold for diagnostic laparoscopy; and isolated or cystic foci, mesenteric pneumatosis, circumferential air-type PI and pneumoperitoneum without peritonitis in a well patient favour conservative management. This pathway has not been prospectively validated and is intended to support, not replace, multidisciplinary judgement.<sup>1,2,6,7,15</sup>

**Table 13.** Proposed structured CT reporting checklist for pneumatosis intestinalis, derived from the findings of this review.

| # | Item         | Content to report                                                                                        |
|---|--------------|----------------------------------------------------------------------------------------------------------|
| 1 | Confirmation | True intramural gas on lung window; exclude pseudopneumatosis (gas trapped between mucosal folds/faeces, |

|    |                        |                                                                                                                           |
|----|------------------------|---------------------------------------------------------------------------------------------------------------------------|
|    |                        | dependent wall)                                                                                                           |
| 2  | Location               | Stomach / duodenum / jejunum / ileum / colon (segments); small-bowel involvement flagged                                  |
| 3  | Extent and morphology  | Focal vs multisegment vs diffuse; isolated/cystic foci vs linear/circumferential; mesenteric pneumatosis                  |
| 4  | Bowel wall enhancement | Normal / decreased / absent, compared with adjacent bowel; contrast phases acquired                                       |
| 5  | Mesenteric vessels     | SMA/SMV/IMA thrombus, embolus, dissection or stenosis; signs of NOMI                                                      |
| 6  | Venous gas             | Mesenteric arcades, segmental veins, SMV, extrahepatic portal vein, intrahepatic portal veins (number of segments)        |
| 7  | Peritoneal findings    | Ascites/free fluid (amount); mesenteric fat stranding/oedema                                                              |
| 8  | Bowel calibre and wall | Dilatation, obstruction, closed loop/volvulus; wall thickening or paper-thin wall                                         |
| 9  | Extraluminal gas       | Pneumoperitoneum, retroperitoneal air, visible wall defect                                                                |
| 10 | Solid organs           | Perfusion defects/infarcts of spleen, liver, kidneys                                                                      |
| 11 | Benign context         | Recent endoscopy/surgery, chemotherapy/steroids/targeted therapy, transplantation, COPD, $\alpha$ -glucosidase inhibitors |
| 12 | Impression             | Reassuring / indeterminate / concerning for ischaemia, with recommendation for clinical correlation                       |

*COPD, chronic obstructive pulmonary disease; IMA, inferior mesenteric artery; NOMI, non-occlusive mesenteric ischaemia; SMA/SMV, superior mesenteric artery/vein.*



*Proposed evidence-informed pathway derived from the pooled estimates of this review; not prospectively validated. ORs = pooled odds ratios for pathologic PI.*

**Figure 29.** Proposed evidence-informed CT appraisal pathway for pneumatosis intestinalis integrating clinical red flags and CT risk categories derived from the pooled estimates of this review (not prospectively validated).

### Strengths

The strengths of this review include its focus on the clinically relevant PI population, the extraction of study-level 2×2 data from full texts verified against the source documents, the complementary use of association and diagnostic accuracy measures, the systematic exploration of heterogeneity and robustness, the formal assessment of small-study effects, the structured synthesis of non-poolable evidence and the grading of certainty for each predictor.

### Implications for research

Future research should prioritise prospective, multicentre cohorts using standardised biphasic CT protocols, predefined imaging definitions (including enhancement grading, venous gas distribution, mesenteric pneumatosis and fat stranding), blinded central reading with interobserver agreement, and a uniform reference standard incorporating operative, histological and follow-up data. Multivariable prediction models combining clinical, laboratory and CT variables should be developed and externally validated in accordance with current reporting standards, and quantitative imaging (iodine maps on dual-energy CT, enhancement ratios and radiomics) deserves evaluation. Individual-participant data meta-analysis would allow adjustment for confounding and the derivation of absolute risks for clinically defined subgroups.

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### CONCLUSIONS AND RECOMMENDATIONS

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In patients with CT-detected pneumatosis intestinalis, decreased or absent bowel wall enhancement and mesenteric arterial or venous occlusion are the CT findings most strongly associated with pathologic, life-threatening PI, followed by portal or portomesenteric venous gas, ascites and small-bowel involvement. Isolated foci of PI favour a benign process, whereas pneumoperitoneum, bowel wall thickening, colonic location, bowel dilatation and multisegment extent alone do not discriminate. Venous gas and vascular occlusion are specific but insensitive, so their absence does not exclude ischaemia.

We recommend that (1) every CT showing PI be reported in a structured manner that explicitly addresses bowel wall enhancement, mesenteric vascular patency, the distribution of venous gas, ascites, location and morphology of PI and extraluminal gas; (2) contrast-enhanced, preferably biphasic CT be obtained whenever renal function permits; (3) CT findings be integrated with clinical and laboratory red flags in a multidisciplinary decision, with surgical exploration for red flags or perfusion-related signs and a trial of close observation for reassuring patterns; and (4) prospective, standardised multicentre studies and externally validated prediction models be undertaken to strengthen the evidence base, which is currently of low to moderate certainty.

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