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Authors: Zingg T, Agri F, Bourgeat M, Yersin B, Romain B, Schmidt S, Keller N, Demartines N

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Avoiding delayed diagnosis of significant blunt bowel and mesenteric injuries: can a scoring tool make the difference? A 7-year retrospective cohort study.

Tobias Zingg [a,*]
Fabio Agri, MD [a, b]
Mylène Bourgeat, PhD [a]
Bertrand Yersin, MD [b]
Benoît Romain, MD, PhD [a, c]
Sabine Schmidt [d]
Nathalie Keller [d]
Nicolas Demartines [a]

[a] Department of Visceral Surgery, Lausanne University Hospital (Centre Hospitalier Universitaire Vaudois – CHUV), Rue du Bugnon 46, 1011 Lausanne, Switzerland
[b] Department of Emergency Medicine, Lausanne University Hospital (Centre Hospitalier Universitaire Vaudois – CHUV), Rue du Bugnon 46, 1011 Lausanne, Switzerland
[c] Department of Digestive Surgery, Strasbourg University Hospital, 1 Avenue Moliere, 67000 Strasbourg, France
[d] Department of Diagnostic and Interventional Radiology, Lausanne University Hospital (Centre Hospitalier Universitaire Vaudois – CHUV), Rue du Bugnon 46, 1011 Lausanne, Switzerland

*Correspondence and reprints:

Tobias Zingg
Lausanne University Hospital (Centre Hospitalier Universitaire Vaudois – CHUV)
Rue du Bugnon 46, 1011 Lausanne, Switzerland
+11 41 79 556 79 43 (Phone)
+11 41 21 314 24 11 (Fax)
tobias.zingg@chuv.ch

ABSTRACT

Introduction: Significant blunt bowel and mesenteric injuries (sBBMI) are frequently missed despite the widespread use of computed tomography (CT). Early treatment improves the outcome related to these injuries. The aim of this study was to assess the prevalence of sBBMI, the incidence of delayed diagnosis and to test the performance of the Bowel Injury Prediction Score (BIPS), determined by the white blood cell (WBC) count, presence or absence of abdominal tenderness and CT grade of mesenteric injury.

Patients and Methods: Single-centre, registry-based retrospective cohort study, screening all consecutive trauma patients admitted to Lausanne University Hospital Trauma Centre from 2008 to 2015 after a road traffic accident. All patients with reliable information about the presence or absence of sBBMI who underwent abdominal CT and for whom calculation of the BIPS was possible were included for analysis. The incidence of delayed (>24 hours after admission) diagnosis in the patient group with sBBMI was determined and the diagnostic performance of the BIPS for sBBMI was assessed.

Results: For analysis, 766 patients with reliable information about the presence or absence of sBBMI were included. The prevalence of sBBMI was 3.1% (24/766). In 24% (5/21) of stable trauma patients undergoing CT, a diagnostic delay of more than 24 hours occurred. Abdominal tenderness ($p<0.0001$) and CT grade ≥4 ($p<0.0001$) were associated with sBBMI, whereas CT grade 4 alone ($p=0.93$) and WBC count ≥17 G/l ($p=0.30$) were not. A BIPS ≥2 had a sensitivity of 89% (95% CI, 67-99), specificity of 89% (95% CI, 86-91), positive likelihood ratio of 8 (95% CI, 6.1-10), negative likelihood ratio of 0.12 (95% CI, 0.03-0.44), positive predictive value (PPV) of 19% (95% CI, 15-24) and negative predictive value (NPV) of 99.7% (95% CI, 98.7-99.9). CT alone identified 79% (15/19) and the BIPS 89% (17/19) of patients with sBBMI ($p=0.66$).

Conclusions: Diagnostic delays in patients with sBBMI are common (24%), despite the routine use of abdominal CT. Application of the BIPS on the present cohort would have led to a high number of non-therapeutic abdominal explorations without identifying significantly more sBBMI early than CT alone.

Keywords: Bowel Injury Prediction Score; BIPS; Blunt bowel and mesenteric injury; Computed tomography; Delayed diagnosis; Laparoscopy; Trauma.

TEXT

Introduction

Early diagnosis for timely treatment of significant blunt bowel and mesenteric injuries (sBBMI) after abdominal trauma can be challenging. This type of injury is relatively rare, with a reported incidence of 1-3% [1-3]. Non-recognized sBBMI is the most frequent cause for delayed laparotomies after blunt abdominal trauma [4] and a diagnostic delay of only five to eight hours has a negative impact on survival [5, 6]. In one study [7], the mortality rate was almost quadrupled when surgical treatment for sBBMI was performed after more than 24 hours after admission. Significant injuries require treatment and include full-thickness perforations, sero-muscular tears and mesenteric lacerations, resulting in bowel ischemia and/or active bleeding [8]. Serosal tears or small hematomas of the bowel wall are considered as non-significant, with perforation occurring in only 0.3% of these patients [7].

CT emerged as the imaging technique of choice for investigating blunt abdominal trauma [9] and is considered as the standard of care for hemodynamically stable patients, with excellent overall sensitivity and specificity for intra-abdominal injuries [10-12]. Despite this, sBBMI can be missed initially, leading to delayed surgical treatment and increased morbidity and mortality [4]. False negative CT rates of up to 13% have been reported for sBBMI [13, 14]. This is an important limitation for the efficient and safe management of blunt abdominal trauma patients, given the potential consequences of a delayed diagnosis. A low threshold for surgical exploration of the abdomen is recommended when there is a clinical suspicion despite the absence of clear signs of sBBMI on CT. However, morbidity rates of 8-41% have been described for non-therapeutic exploratory laparotomies [15-19]. Laparoscopy is a minimally invasive alternative to laparotomy with fewer reported associated complications [20]. In unclear cases, the surgeon must weigh the risks associated with a diagnostic delay against the risks associated with a non-therapeutic intervention.

To optimize decision-making and select patients with unclear CT-findings appropriately for early surgical exploration or safe observation, several tools predictive for sBBMI have been proposed [21-24]. The recently published “Bowel Injury Prediction Score” (BIPS) [23] can be obtained in the emergency department (ED) and is based on the presence or absence of abdominal tenderness, the white blood cell (WBC) count and the CT grade of mesenteric injury. Its originally reported sensitivity and specificity for sBBMI are 86% and 76% respectively, with a positive predictive value (PPV) of 71% and a negative predictive value (NPV) of 89%. Patients with a BIPS ≥2 had a 19 times higher risk of sBBMI than patients with a lower score [23]. However, when applied to a retrospective series of 16 patients with surgically proven sBBMI [25], the BIPS was found to have a sensitivity of only 56%.

The primary aim of the present study was to determine the incidence of delayed diagnosis of sBBMI in a patient cohort with a representative prevalence of sBBMI. The secondary aim was to evaluate the performance of the BIPS when applied to a cohort with known presence or absence of sBBMI.

Patients and Methods

This was a single-centre, registry-based retrospective cohort study, prepared to conform to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [26]. It was based on the prospective trauma registry of Lausanne University Hospital (Centre Hospitalier Universitaire Vaudois - CHUV), including all consecutive patients over sixteen years old admitted to the trauma resuscitation area of the emergency department (ED) following a road traffic accident (RTA) from January 2008 to June 2015. Patients with an initial observation period of less than 24 hours [27] without consecutive follow-up and patients with unavailable information about the presence or absence of sBBMI were excluded. The study protocol was approved by the local institutional review board (Protocol No 2016-00928).

Demographic data, admission Glasgow Coma Scale (GCS) score, Injury Severity Score (ISS), hospital length of stay (LOS), mortality, diagnosis of sBBMI, concomitant abdominal organ and/or bony injuries and types of therapeutic intervention were obtained. Furthermore, data included all items necessary to obtain the BIPS [23], which includes the white blood cell (WBC) count, abdominal tenderness and the CT-grade of mesenteric injury. A BIPS of ≥2 was used as threshold as in the original work. For calculation of the BIPS (range = 0-3), one point was given for WBC counts of ≥17 G/l, one point for the presence of abdominal tenderness and one point for a CT grade of ≥4, respectively. **Table 1** shows the BIPS CT grading scale [23].

Data were extracted from our prospective trauma registry and when unavailable (abdominal tenderness) were collected from the electronic patient record. The results of forensic autopsies (FA) were obtained with the permission of the Attorney General. All available clinical data, laboratory results and CT images were obtained and recorded during the initial phase of care in the ED. The Lausanne University Hospital trauma protocol follows the Advanced Trauma Life Support (ATLS®) [28] guidelines, specifically adapted to the local infrastructure and resources. Imaging in the trauma resuscitation area includes plain films of the chest and pelvis. All hemodynamically unstable patients also undergo a Focused Assessment with Sonography for Trauma (FAST) exam. Stable patients undergo a whole-body contrast-enhanced CT, unless there is no clinical indication as judged by the attending trauma surgeon. Unstable patients with a positive FAST are taken to the operating room (OR) for laparotomy. In these patients, whole-body CT is performed after life-saving procedures and hemodynamic stabilization. Angio-embolisation (AE) is performed depending on the decision of the attending trauma surgeon for stable patients with isolated mesenteric bleeding on CT. The physical exam was performed by the attending trauma surgeon in charge. Since physical exam was considered unreliable for intubated patients under the effect of sedation and neuromuscular blocking agents, the abdominal pain component of the score was considered as missing for analysis of the BIPS performance.

The institutional polytrauma CT protocol was performed with a 64-detector row CT (Light Speed VCT 64 Pro; GE Healthcare, Milwaukee, WI, USA). 1.25 mm reconstructed axial slices with increments of 1 mm were obtained during the arterial phase (25s) centred on the thorax, and 2.5 mm reconstructed axial slices with increments of 2 mm were obtained during the venous phase (80s) centred on the abdomen and pelvis, after intravenous injection of iodinated contrast medium Accupaque® at a flow rate of 4 ml/s (120 kV, 300 mA, table speed 55mm per rotation (0.8s), pitch 1.375). Automatic tube current modulation in all three axes (SmartmA) was used as well as iterative reconstruction algorithm ASIR. For all patients who underwent abdominal CT, images were independently reviewed for BIPS CT injury grades 4 and 5 according to McNutt [23] by two experienced radiologists (NK and SS), who were blinded to the original CT reports and to patient outcomes.

The two main patient groups were defined based on the presence or absence of sBBMI. The latter included all patients with non-significant BBMI (nsBBMI) and complete absence of BBMI, since the distinction between these was clinically irrelevant. BBMI requiring either surgical treatment or interventional radiology (IR), or obvious BBMI documented at FA were considered as significant (sBBMI). Patients who had none of the above, but who were alive at discharge after an observation period of more than 24 hours were considered not to have sBBMI. Operative report findings from surgical abdominal exploration or AE for mesenteric bleeding and autopsy report findings were considered reliable information on the presence or absence of sBBMI.

Statistical and graphic analyses were performed using R software version 3.3.1 [29]. For qualitative variables results were expressed in frequencies and percentages. For continuous variables, a measure of dispersion was given using median, with lower and upper interquartile ranges. Qualitative variables were compared using Fisher's exact test. Continuous variables were compared using Student's *t*-test when distribution was bell shaped and they were compared using a Mann-Whitney U test if distribution was skewed. A significance threshold with a *p*-value of 0.05 was adopted for all statistical analyses. Receiver operating characteristic (ROC) curve was used to identify the optimal cut-off for the BIPS. Sensitivity, specificity, PPV, NPV and diagnostic accuracy at the optimal cut-off threshold score were derived from the ROC.

Results

From January 2008 to June 2015, 838 patients were admitted to the trauma resuscitation area of Lausanne University Hospital (CHUV) ED following RTAs. **Figure 1** shows the exclusion flowchart with the main patient groups. In the group of 766 patients with reliable information on BBMI status, the prevalence of sBBMI was 3.1% (24/766) and 21% (5/24) of these had a delay in diagnosis of more than 24 hours. The overall mortality rate in this group was 2.1% (16/766). Mortality in patients with sBBMI and early diagnosis was 5.3% (1/19), versus 40% (2/5) in patients with delayed diagnosis (p=0.20). **Table 2** summarizes information on the 24 patients with sBBMI. Non-significant BBMI (nsBBMI) was present in at least 56 of the 742 patients without significant injuries, summarized in **Table 3**.

Mortality, median ISS, median BIPS and median LOS were significantly higher in patients with sBBMI. Diaphragm and long bone injuries were associated with sBBMI in univariate analysis. The characteristics of the groups with and without sBBMI are summarized in **Table 4**.

Patient management

Surgical treatment for significant intra-abdominal injuries was required in 4.3% (33/766) of patients, of which 61% (20/33) had a sBBMI. The most frequent sBBMI were active bleeding from a mesenteric vessel and bowel perforation, either isolated or in association. **Table 5** summarizes all types of injuries present at surgical exploration. The remaining 39% (13/33) of patients without any BBMI underwent laparotomy and had interventions for solid organ injury (SOI) and diaphragm repair, summarized in **Table 6**. Of the patients undergoing surgical treatment for sBBMI, 10% (2/20) died, versus 31% (4/13) of patients who were operated for abdominal injuries other than sBBMI (p=0.29).

For the 20 patients with sBBMI undergoing surgical exploration of the abdomen, the median time interval from ED arrival to operation was 2.3 hours (IQR 1.5-7.4). Surgical treatment eventually required laparotomy in 80% (16/20) of patients with sBBMI. The initial surgical approach was laparoscopic in 41% (7/17) of hemodynamically stable patients, which allowed for definitive treatment in four and required conversion to laparotomy in three. Early laparoscopy was performed for sBBMI identified by CT in four patients, of whom one required conversion to laparotomy.

Surgical exploration was delayed in 20% (4/20) of patients with sBBMI, with a median time interval of 42 hours (IQR 27-58). In three of these diagnostic laparoscopy, and in one laparotomy was performed for clinical deterioration. Laparoscopy was therapeutic in one case, two required conversion to laparotomy. All three required bowel resection, one for perforation, two for ischemia. All patients who underwent laparoscopy survived and no procedure-related complications occurred. Mortality in patients undergoing early surgery was 6.3% (1/16) versus 25% (1/4) in patients with delayed surgery (p=0.74).

AE was performed in three patients for isolated active mesenteric bleeding seen on CT. Haemostasis was successful in all three cases with a median time interval from ED arrival to embolization of 74 minutes (IQR 71-80). All three survived, but one patient who was bleeding from the sigmoid artery developed large bowel ischemia after AE, subsequently required laparotomy for segmental colectomy and survived.

CT performance

In three unstable patients undergoing laparotomy without prior CT, sBBMI was found, leaving 21 patients (3%) with sBBMI in the sub-population who underwent CT (n=708).

Specific CT signs of sBBMI (as in BIPS CT grade 5) were present in 76% (16/21) of patients. Surgical management was delayed in two of these. In the first patient a pneumoperitoneum, in the second patient active bleeding from the transverse mesocolon were visible but not recognized on CT. The first patient underwent laparoscopic small bowel resection for ischemia on the second day post-admission and survived to discharge. The second patient underwent laparotomy on the second day post admission where a massive hemoperitoneum was found. This patient eventually died from multiple organ failure. The remaining 14 patients with specific signs of sBBMI underwent either surgery (n=11) or AE (n=3) without delay. Among the 14 patients with early diagnosis, there was one death due to severe head injury.

Radiological abnormalities compatible with, but not diagnostic of, sBBMI were present in 19% (4/21) of patients with sBBMI who thus had no straightforward radiological indication for intervention. A delay in diagnosis of more than 24 hours was present in two of these patients who both had free abdominal fluid without SOI. Of these two patients, one, who eventually died 36 hours after admission, had a sero-muscular tear and a wall hematoma of the colon, found at FA along with a grade I splenic injury, multiple pulmonary contusions, a pelvic fracture and a severe traumatic brain injury. The second patient, who survived, underwent diagnostic laparoscopy for clinical deterioration on the second day post admission, was converted to laparotomy and found to have small bowel perforations requiring suture repair and sigmoid colon ischemia requiring colectomy with end colostomy.

CT showed no signs of BBMI in 5% (1/21) of patients with sBBMI. This patient had a delay of more than 24 hours before undergoing exploratory laparoscopy (for clinical deterioration) which was converted to laparotomy for resection of segmental small bowel ischemia resulting from a non-bleeding mesenteric injury.

Free abdominal fluid was present on CT in 81% (17/21) of patients with sBBMI, versus 14% (98/687) of patients without sBBMI (odds ratio, 26; 95% CI, 8.4-78; $p<0.0001$). No SOI was present in 65% (11/17) of patients with sBBMI and free abdominal fluid. Free fluid without SOI had a stronger association with sBBMI compared to free fluid with SOI (odds ratio, 8.7; 95% CI, 2.8-27, $p=0.0003$).

BIPS performance

Of the 708 patients who underwent abdominal CT, only patients with complete datasets and patients with incomplete datasets in whom the final BIPS was either ≥2 (positive) or <2 (negative), independent of the missing item, were included. Missing score items potentially modifying the final BIPS to ≥2 were present in 46 (6.5%) patients.

The BIPS was calculated for the remaining 662 patients among whom there were 19 with sBBMI. The area under ROC curve was 91.4% (95% CI, 84-99) with the best cut-off at 2 points (**Figure 2**). The BIPS (≥2) had a sensitivity of 89% (95% CI, 67-99), specificity of 89% (95% CI, 86-91), positive likelihood ratio of 8 (95% CI, 6.1-10), negative likelihood ratio of 0.12 (95% CI, 0.03-0.44), PPV of 19% (95% CI, 15-24) and a NPV of 99.7% (95%

CI, 98.7-99.9). Patients with a BIPS ≥2 were 67 times more likely to have a sBBMI than patients with a BIPS <2 (odds ratio, 67; 95% CI, 15-298; *p*<0.0001).

When the BIPS cut-off was set to ≥1, sensitivity increased to 95% (95% CI, 75-99.9). Specificity dropped to 60% (95% CI, 56-63), positive likelihood ratio to 2.4 (95% CI, 2.1-2.7), negative likelihood ratio to 0.08 (95% CI, 0.01-0.57), and PPV to 6.4% (95% CI, 5.7-7.3). The NPV slightly increased to 99.8% (95% CI, 98.4-100). Setting the cut-off to 3 decreased the sensitivity to 29% (95% CI, 11-52). Specificity increased to 99% (95% CI, 98-99.7), positive likelihood ratio to 32 (95% CI, 11-91), negative likelihood ratio to 0.7 (95% CI, 0.6-0.9) and PPV to 50% (95% CI, 26-74). The NPV decreased to 98% (95% CI, 97-98).

CT alone identified 79% (15/19) and the BIPS 89% (17/19) of patients with sBBMI (*p*=0.66). A false negative BIPS was present in two patients, of which one, with a BIPS of 1 for abdominal tenderness and a normal CT, had a delay in diagnosis. The second patient, with a BIPS of 0, underwent early diagnostic laparoscopy for the presence of free fluid without SOI. When applied to patients with sBBMI and unspecific CT signs (3/19), the BIPS was ≥2 in two, and <2 for the one patient with no CT signs (1/19).

Association of BIPS items with sBBMI

Bowel Injury Prediction Scores of 3 were false positive in half of the cases (6/12). A BIPS of 2 was present in 77 patients with either a documented absence of abdominal tenderness, a WBC count <17 or a BIPS CT injury grade <4. When resulting from the presence of abdominal tenderness and a CT grade ≥4 only (n=26), the BIPS was false positive in 58% (15/26) of cases, all with a BIPS CT injury grade of 4. All 11 true positive cases had a BIPS CT injury grade of 5. When resulting from a WBC count ≥17 and either the presence of abdominal tenderness only (n=34) or a CT grade ≥4 only (n=17), the BIPS was false positive in all cases.

Of the three elements of the BIPS score, only the presence of abdominal tenderness (odds ratio, 69; 95% CI, 9-516; *p*<0.0001) and CT grade ≥4 (odds ratio, 76; 95% CI, 22-268; *p*<0.0001) were associated with sBBMI, but not WBC count ≥17 G/l (*p*=0.30). When further separating the CT grade ≥4 item into grades 4 and 5, CT grade 4 alone (*p*=0.93) was not associated with sBBMI in the present series, unlike CT grade 5 (*p*<0.0001), which is diagnostic of sBBMI. **Table 7** summarizes the associations of the BIPS, its individual score items and free fluid on CT with the presence or absence of sBBMI.

When patients with pathognomonic CT signs for sBBMI (BIPS CT grade 5) were excluded (n=15), the BIPS (≥2) had a sensitivity of 50% (95% CI, 8-93), specificity of 89% (95% CI, 86-91), positive likelihood ratio of 4.5 (95% CI, 1.6-12), negative likelihood ratio of 0.6 (95% CI, 0.2-1.5), PPV of 2.7% (95% CI, 1-7) and a NPV of 99.6% (95% CI, 99.1-99.9).

Discussion

The results of the present series show that sBBMI in general are associated with an increased mortality rate and indicate that delays in diagnosis and treatment of sBBMI are not uncommon despite the widespread use of abdominal CT, which is considered as the standard diagnostic modality in hemodynamically stable trauma patients. A normal CT has been shown to have a high negative predictive value for blunt abdominal injuries [12] and for BBMI, a sensitivity of 88-95% and a specificity of more than 99% have been described [13, 30]. In the present series, 24% (5/21) of patients with sBBMI who had undergone a CT were diagnosed more than 24 hours after arrival in the ED, but unlike Fakhry et al. [5], we did not find a significant difference in mortality rates between patients with early and delayed diagnosis (5.3% versus 40%, p=0.20), but this is likely due to the small number of sBBMI cases.

In retrospect two of the five diagnostic delays were clearly avoidable because pathognomonic signs of sBBMI (active mesenteric bleeding in one, pneumoperitoneum in the other) were present but not recognized on the initial CT, underscoring the importance of careful examination and interpretation of obtained CT images. In two other patients with delayed diagnosis, free abdominal fluid without SOI was present on CT. The presence of free abdominal fluid on CT increased the risk of sBBMI by 26-fold in the present cohort. Patients with free fluid and no SOI on CT had an almost ninefold increase in risk of sBBMI compared to patients with free fluid in the presence of SOI. In a study by Petrosoniak et al. [31], all patients with sBBMI had free fluid when a 64-slice CT was used. The only patient with sBBMI in the present series who had a normal CT (5%), also had a delayed diagnosis. Fakhry et al. [7] described a false negative rate of 13% for the CT diagnosis of perforated small bowel injury. In a recent series of patients with surgically proven sBBMI, LeBedis et al. [25] found a false negative CT rate of 9.1%.

Systematic surgical exploration of symptomatic or obtunded patients with equivocal CT findings for sBBMI might allow for early treatment of all sBBMI. But complication rates of 8-41% for non-therapeutic laparotomies have been described in the literature [15-19]. To avoid delayed diagnosis and non-therapeutic interventions in patients with unclear CT findings, several risk scores have been developed. To our knowledge, this is the first study to evaluate the performance of the BIPS [23]. Contrary to what was observed in the original study, no association between WBC counts ≥17 or CT injury grades 4 and sBBMI was found in the present study. All BIPS equal to two who resulted from WBC counts ≥17 and either the presence of abdominal tenderness or CT grades ≥4 were false positives, explaining the low positive predictive value of a BIPS ≥2 in the present series. Schnüriger et al. [21] have also found a rather poor predictive value for WBC counts to predict hollow viscus injury in a series of 5950 patients. The absent association of CT grade 4 with sBBMI in the present study was "compensated" by the presence of cases with CT grade 5, which is extremely specific for sBBMI, so that CT grade ≥4 remained associated with sBBMI.

When a pneumoperitoneum, vascular or intestinal contrast extravasation is present on CT, a significant sBBMI is almost invariably present. A score has no utility for these patients, CT alone being diagnostic. Interestingly, in the present series one intubated patient with a BIPS CT injury grade 5 and a WBC count <17 G/l may theoretically have ended up with a false negative BIPS, even though the CT was diagnostic of sBBMI. Patients with potential benefit from a score are those with unspecific or absent CT signs. We therefore think that the CT item of the BIPS should only include grade 4 injuries. When applied to patients without "hard" signs for sBBMI on CT only, the sensitivity of the BIPS actually dropped from 89% to 50%.

Had the BIPS, when available, been applied to all patients with sBBMI, three out of four patients with diagnostic delay and two out of three patients with unspecific CT signs would have been correctly identified as at risk, but only at the price of an inappropriately high number of non-therapeutic abdominal explorations. The BIPS would have failed to recognize the likelihood of injury for the one patient with no CT signs of sBBMI.

Faget et al. [22] have proposed a scoring system exclusively based on 9 CT criteria, with a sensitivity of 96%, a specificity of 92%, a PPV of 56% and a NPV of 99.6%. The strength of this score is that all items are objective and easily available from a single source of information. Zarour et al. [24] developed the "Z-score" for patients without SOI. It is based on CT signs (free fluid and signs of bowel injury) and clinical findings (graded abdominal tenderness and abdominal wall bruising). A Z-score >9 was found to be an independent predictor for the need of exploratory laparotomy [24]. Given the grading of the abdominal tenderness component in that study, it was not possible to reliably determine the Z-score and evaluate its performance using a retrospective study design.

The value of physical examination for the diagnosis of sBBMI is unclear. In the present study, the presence of abdominal tenderness increased the risk of sBBMI. An often-described clinical sign predictive of sBBMI is the seat-belt sign. Some studies reported intestinal injuries in patients with a seat-belt sign in up to 15% [32, 33], whereas others, including McNutt et al. [23] found no significant association [12, 34, 35]. In the present study, the value of the seat-belt sign was not analysed because, unlike abdominal tenderness, the presence or absence of abdominal contusion marks was not systematically documented in the patient record.

Most patients (61%) who underwent surgical exploration in the present series had sBBMI. This likely represents selection due to the high success rate of non-operative management for even high-grade SOI. Of the 17 hemodynamically stable patients with sBBMI in our series who were operated, seven underwent exploratory laparoscopy of which more than half were therapeutic, three required conversion to laparotomy. This is higher than the pooled overall conversion rate of 24% observed by Li et al. [20] in their recent meta-analysis. In a more specific study by Mathonnet et al. [36], 15 patients with blunt small bowel perforations underwent laparoscopy of which 10 required conversion to laparotomy for either suture repair or resection, five could be definitely treated by laparoscopy. Diagnostic laparoscopy in the context of abdominal trauma has been shown to be safe with very little associated morbidity and mortality [20, 36-39]. In the present series, all patients who underwent laparoscopy survived and no procedure related complications occurred.

AE was performed for isolated active mesenteric bleeding in 13% (3/24) of the present patient cohort. In analogy to the non-operative management of SOI, AE is increasingly used to treat active bleeding from other sources, including mesenteric vessels. Recently, Shin et al. [40] published 10 cases of traumatic mesenteric bleeding undergoing AE, with a success rate of 90% and no ischemic complications. This is in contrast with the present findings, since one of the three patients who underwent successful haemorrhage control with AE developed bowel ischemia and required segmental colon resection followed by a complicated postoperative course.

The present work has obvious limitations inherent to its retrospective nature. Data accuracy is subject to documentation errors in the trauma registry and patient record. An existing score was applied to a new retrospective cohort, but for the latter, only patients with well documented score variables and certainty about the presence or absence of sBBMI were included. For most patients, the distinction between the presence of nsBBMI and the complete absence of BBMI could not be made, but this was clinically irrelevant. Finally, the study population is a selection of patients after RTAs. Although this is the most frequent blunt injury mechanism worldwide and for sBBMI in particular, the results of the present study cannot be generalised to all blunt trauma patients.

Conclusions

A diagnostic delay occurs in one of four patients with sBBMI, despite the routine use of abdominal CT. While the high NPV of 99.7% of a BIPS ≥2 may allow for close patient observation, its PPV of 16% would lead to a high number of non-therapeutic abdominal explorations without identifying sBBMI earlier than CT alone.

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Figure 1. Flow diagram showing the main groups of the patient cohort

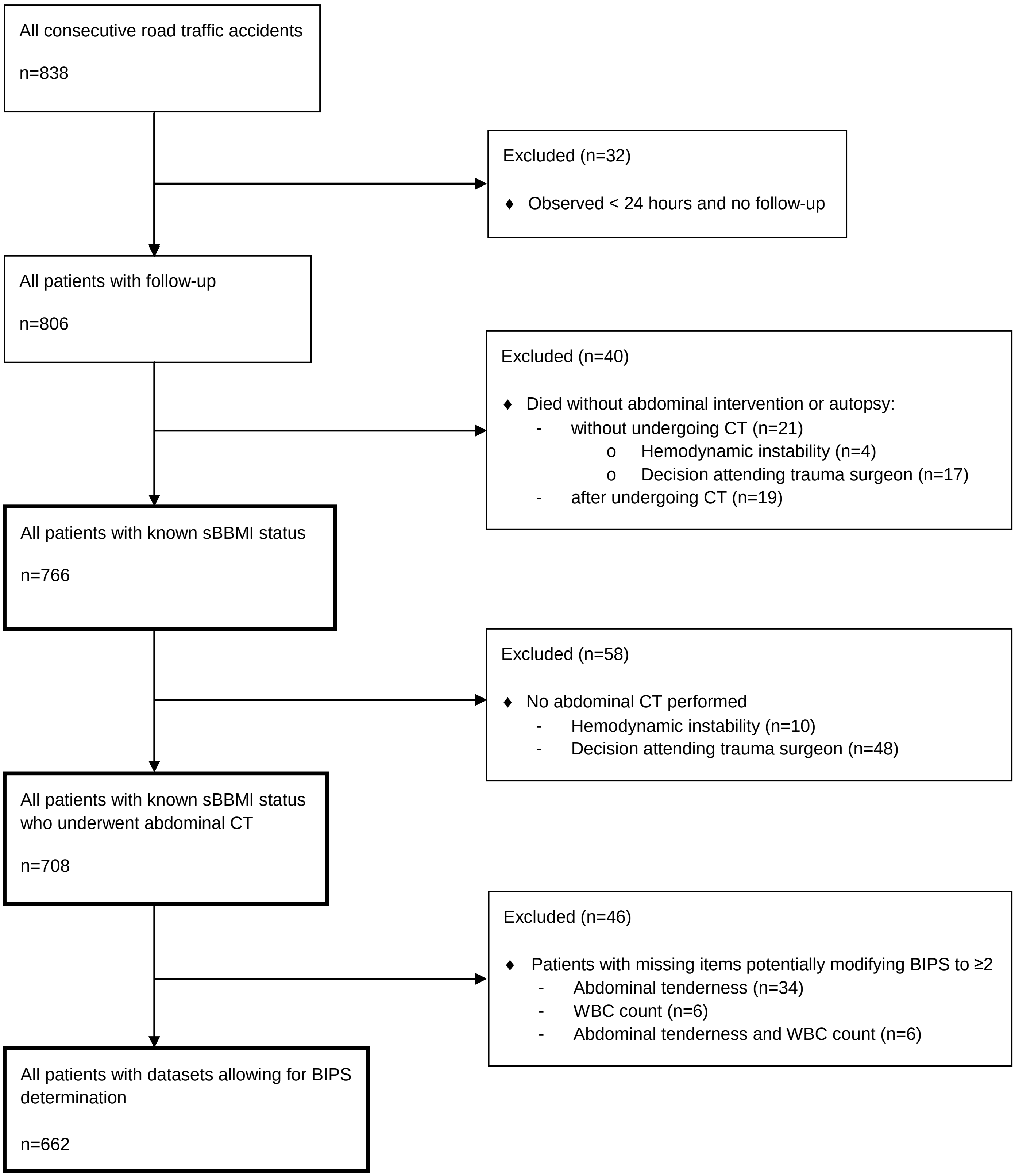

Figure 2. ROC curve for the Bowel Injury Prediction Score (BIPS) ≥2 for significant Blunt Bowel and Mesenteric (sBBMI) injuries, with the best cut-off at 2 points. Area Under Curve (AUC) = 91.4% (95% CI, 84.4-98.5).

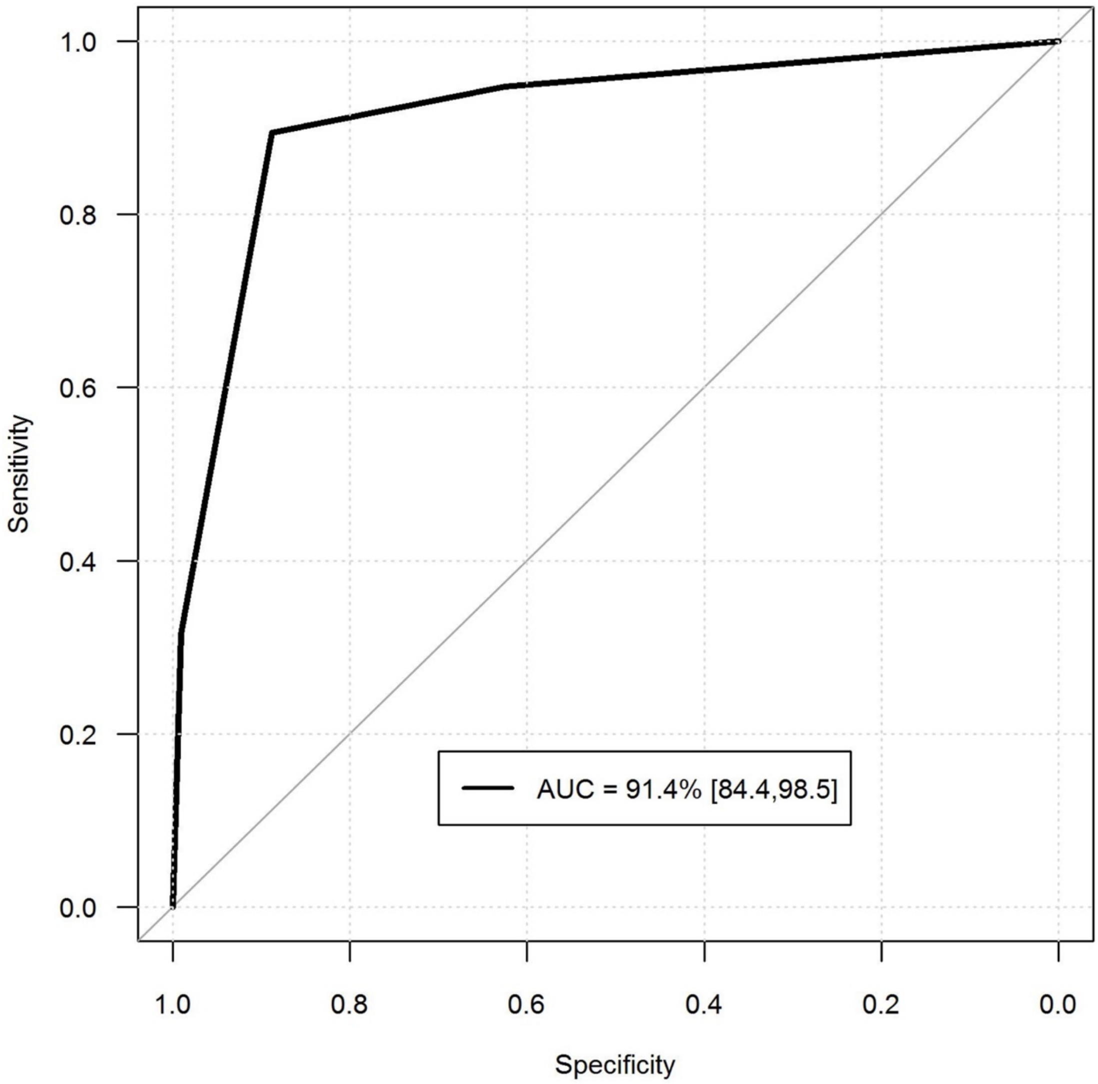

Table 1. BIPS CT Grading Scale for Mesenteric Injury (McNutt et al.) [23]

Grade	Description
1	Isolated mesenteric contusion without associated bowel wall thickening or adjacent interloop fluid collection
2	Mesenteric hematoma < 5 cm without associated bowel wall thickening or adjacent interloop fluid collection
3	Mesenteric hematoma > 5 cm without associated bowel wall thickening or adjacent interloop fluid collection
4	Mesenteric contusion or hematoma (any size) with associated bowel wall thickening or adjacent interloop fluid collection
5	Active vascular or oral contrast extravasation, bowel transection or pneumoperitoneum

BIPS=Bowel Injury Prediction Score, CT=Computed Tomography.

Table 2. All patients with sBBMI (n=24)

	Details of sBBMI	Other organ injury	CT signs of BBMI	Interventions	Delay >24 h	Outcome
1	Sero-muscular colon injury, mesenteric hematoma	Spleen	FAF without SOI	No intervention. Underwent forensic autopsy	x	Died
2	Bleeding mesenteric vessel, colon perforation	Spleen, liver	Active mesenteric bleeding, FAF without SOI	Colon and mesenteric suture, splenectomy, liver packing (LT)		Died
3	Large mesenteric hematoma	-	Active mesenteric bleeding*, FAF without SOI	Lavage, temporary abdominal closure (LT)	x	Died
4	Mesenteric injury with small bowel ischemia	-	No signs of BBMI, no FAF, DxLS	Small bowel resection (LT)	x	Survived
5	Mesenteric injury with colon ischemia, small bowel perforation	-	FAF without SOI, DxLS	Colectomy, small bowel suture (LT)	x	Survived
6	Small bowel perforation, mesenteric hematoma	-	Pneumoperitoneum*, FAF without SOI	Small bowel resection (LS)	x	Survived
7	Bleeding mesenteric vessel	Liver	No CT (unstable)	Mesenteric suture, liver suture (LT)		Survived
8	Bleeding mesenteric vessel with small bowel ischemia	-	No CT (unstable)	Small bowel resection (LT)		Survived
9	Bleeding mesenteric vessel	Adrenal	No CT (unstable)	Mesenteric suture (LT)		Survived
10	Sero-muscular colon injury	Spleen, diaphragm	Pneumoperitoneum, no FAF, left diaphragm rupture	Colon suture, splenectomy, diaphragm suture repair (LT)		Survived
11	Bleeding mesenteric vessel, mesenteric hematoma	Liver	Active mesenteric bleeding, FAF with SOI	Mesenteric suture, liver packing (LT)		Survived
12	Colon perforation	Spleen	Pneumoperitoneum, FAF with SOI	Colectomy (LT)		Survived
13	Colon and small bowel perforation	Spleen, kidney	Mesenteric stranding, FAF with SOI	Colectomy, small bowel suture (LT)		Survived
14	Bleeding mesenteric vessel, mesenteric hematoma	-	Active mesenteric bleeding, FAF without SOI	Mesenteric suture (LT)		Survived
15	Bleeding mesenteric vessel, small bowel perforation	Diaphragm	Pneumoperitoneum, FAF without SOI	Small bowel resection, diaphragm suture repair (LT)		Survived
16	Colon perforation	Liver, pancreas	Pneumoperitoneum, FAF with SOI	Colectomy (LT)		Survived
17	Bleeding mesenteric vessel, small bowel perforation	-	Active mesenteric bleeding, FAF with SOI, DxLS	Mesenteric suture, small bowel suture (LT)		Survived
18	Bleeding mesenteric vessel	-	Mesenteric stranding, FAF without SOI	Mesenteric suture (LS)		Survived
19	Bleeding mesenteric vessel	Kidney	Active mesenteric bleeding, FAF without SOI	Mesenteric suture (LS)		Survived
20	Bowel perforation (non-localized)	-	Pneumoperitoneum, FAF without SOI	Lavage-drainage (LS)		Survived
21	Small bowel perforation	-	Pneumoperitoneum, FAF without SOI	Small bowel suture (LT)		Survived
22	Pseudoaneurism with bleeding mesenteric vessel	-	Active mesenteric bleeding, no FAF	AE left colic artery branch		Survived
23	Bleeding mesenteric vessel	Liver	Active mesenteric bleeding, FAF with SOI	AE inferior mesenteric artery branch		Survived
24	Bleeding mesenteric vessel	-	Active mesenteric bleeding, no FAF	AE inferior mesenteric artery branch		Survived

AE = Angio-Embolization, DxLS = Diagnostic Laparoscopy, FAF = Free Abdominal Fluid, LT = Laparotomy, LS = Laparoscopy, sBBMI = significant Blunt Bowel and Mesenteric Injury, SOI = Solid Organ Injury.
*visible, but not recognized on CT.

Table 3. All patients without sBBMI (n=742)

Intervention (n=742)	nsBBMI (n≥53)	no BBMI (n≤689)	Outcome
Forensic autopsy (n=9)	Small patchy mesenteric hematomas (n=3)	(n=6)	Died
Laparotomy for SOI (n=13)	None	(n=4)	Died
		(n=9)	Survived
No intervention (n=720)	(n≥50)*	Unknown (n≤670)	Survived

BBMI=Blunt Bowel and Mesenteric Injury, nsBBMI=non-significant BBMI, sBBMI=significant BBMI, SOI = Solid Organ Injury.
*50 cases with radiological findings of BIPS CT injury grade 4 at Computed Tomography.

Table 4. Characteristics of the patient groups with and without sBBMI (n=766)

n (%)	**sBBMI + 24 (3.1)**	**sBBMI - 742 (96.9)**	***p***
Age (years), median (IQR)	40 (24-58)	36 (23-52)	0.21
Male, n (%)	17 (71)	550 (74)	0.87
ISS, median (IQR)	18 (13-34)	14 (9-24)	0.02
GCS, median (IQR)	15 (14-15)	15 (9-15)	0.12
BIPS (total), median (IQR)	2 (2-3)	0 (0-1)	<0.0001
Lactate (mmol/l), median (IQR)	2.3 (1.5-3.6)	1.9 (1.2-2.8)	0.09
WBC count (G/l), median (IQR)	16 (12-19)	13 (9.6-17)	0.09
LOS (days), median (IQR)	21 (5-39)	9 (3-20)	0.002
Mortality, n (%)	3 (13)	13 (1.8)	0.02
Associated abdominal injuries: n (%)			
Any abdominal organ injury	16 (67)	159 (21)	<0.0001
Spleen	5 (21)	68 (9.2)	0.14
Liver	5 (21)	53 (7.1)	0.06
Kidney	2 (8.3)	24 (3.2)	0.39
Adrenal	1 (4.2)	8 (1)	0.50
Pancreas	1 (4.2)	2 (0.3)	0.18
Bladder	0	3 (0.4)	1
Diaphragm	2 (8.3)	1 (0.1)	0.01
Associated fractures: n (%)			
Pelvis	7 (29)	101 (14)	0.08
Spine	3 (13)	184 (25)	0.25
Ribs	9 (38)	201 (27)	0.37
Extremities (long bones)	13 (54)	237 (32)	0.04

BIPS=Bowel Injury Prediction Score, sBBMI=significant Blunt Bowel and Mesenteric Injury, WBC=White Blood Cells, CT=Computed Tomography, LOS= Length of Stay.
Continuous data are presented as median (Interquartile Range), categorical data as n (%).

Table 5. Abdominal injuries in operated patients (n=33)

Intraoperative findings	sBBMI only (n=10)	sBBMI with SOI (n=10)	SOI only (n=13)
sBBMI:			
Bleeding mesenteric vessel (n=4)	1	3	-
Bleeding mesenteric vessel & bowel perforation (n=3)	1	2	-
Bleeding mesenteric vessel & bowel ischemia (n=1)	1	-	-
Bleeding mesenteric vessel & hematoma (n=2)	1	1	-
Bowel perforation (n=5)	2	3	-
Sero-muscular colon injury (n=1)	-	1	-
Bowel perforation & mesenteric hematoma (n=1)	1	-	-
Bowel ischemia & perforation (n=1)	1	-	-
Bowel ischemia (n=1)	1	-	-
Large mesenteric hematoma (n=1)	1	-	-
Other abdominal injuries:			
Spleen (n=7)	-	1	6
Liver (n=5)	-	2	3
Kidney (n=1)	-	1	-
Adrenal (n=1)	-	1	-
Diaphragm (n=1)	-	1	-
Spleen-Liver combined (n=4)	-	1	3
Spleen-Diaphragm combined (n=2)	-	1	1
Spleen-Kidney combined (n=1)	-	1	-
Liver-Pancreas combined (n=1)	-	1	-
Spleen all	-	4	10
Liver all	-	4	6
Diaphragm all	-	2	1

sBBMI = significant Blunt Bowel and Mesenteric Injury, SOI = Solid Organ Injury.

Table 6. Abdominal procedures in patients undergoing surgery (n=33)

Intervention	Laparotomy (n=29)		Laparoscopy (n=4)
	sBBMI (n=16)*	no sBBMI (n=13)	sBBMI (n=4)
Mesenteric suture	6	-	2
Bowel suture	6	-	0
Bowel resection	7	-	1
Lavage	1	-	1
Splenectomy	2	9	0
Splenorrhaphy	0	1	0
Liver packing/suture	3	4	0
Partial hepatectomy	0	1	0
Diaphragm repair	2	1	0

sBBMI = significant Blunt Bowel and Mesenteric Injury
*3/16 converted from laparoscopy

Table 7. Association of BIPS, individual BIPS items and free fluid on CT with sBBMI

	sBBMI + **n (%)**	**sBBMI -** **n (%)**	***p***
(n=662)	**19**	**643**	
BIPS ≥2	17 (89)	72 (11)	<0.0001
- BIPS 3	6 (32)	6 (0.9)	<0.0001
- BIPS 2	11 (58)	66 (10)	<0.0001
BIPS <2	2 (11)	571 (89)	<0.0001
- BIPS 1	1 (5)	169 (26)	0.06
- BIPS 0	1 (5)	402 (63)	<0.0001
(n=610)	**21**	**589**	
Abdominal tenderness	20 (95)	133 (23)	<0.0001
(n=723)	**23**	**700**	
WBC count ≥17 G/l	9 (39)	189 (27)	0.30
(n=708)	**21**	**687**	
CT Grade ≥4	18 (86)	50 (7)	<0.0001
- CT Grade 4	2 (10)	50 (7)	0.93
- CT Grade 5	16 (76)	0 (0)	<0.0001
Free fluid on CT	17 (81)	98 (14)	<0.0001
- Without SOI	11 (52)	17 (2)	<0.0001
- With SOI	6 (29)	81 (12)	0.07

BIPS=Bowel Injury Prediction Score, CT=Computed Tomography, LOS= Length of Stay, sBBMI=significant Blunt Bowel and Mesenteric Injury, SOI=Solid Organ Injury, WBC=White Blood Cells.