

Diagnostic Performance of Ct Cystography in Blunt Bladder Trauma: A Single-Center Study

Le Thi Linh

Vinh Medical University, Nghean, Vietnam

Abstract

Background

Bladder injury is an uncommon but clinically important consequence of blunt abdominopelvic trauma. Accurate and timely diagnosis is essential because the type and location of bladder injury influence subsequent management. Computed tomography (CT) cystography allows direct visualization of contrast extravasation and simultaneously provides information about associated intra-abdominal and pelvic injuries.

Objectives

To evaluate the diagnostic performance of CT cystography for detecting bladder injury in patients with blunt abdominal trauma and to assess the diagnostic value of selected CT findings for characterizing bladder injury.

Materials and Methods

This cross-sectional descriptive study included 22 patients with suspected bladder injury following blunt abdominal trauma who underwent multidetector CT with retrograde CT cystography at Friendship General Hospital of Nghe An, Vietnam. CT examinations included routine abdominal and pelvic CT followed by retrograde filling of the urinary bladder with diluted water-soluble contrast material. CT findings were interpreted by two radiologists with more than 5 years of experience. Surgical or cystoscopic findings were used as the reference standard. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy were calculated from 2×2 contingency tables. Exact 95% confidence intervals (CIs) were calculated for diagnostic proportions.

Results

Among the 22 patients, 20 were men and 2 were women, with a mean age of 43 years. Traffic accidents were the most frequent cause of injury, accounting for 77.3% of cases. Gross hematuria and suprapubic pain were present in 100% and 95.5% of patients, respectively. Bladder wall discontinuity was identified in 21 patients (95.5%), and contrast extravasation was observed in 21 patients. According to the reference standard, 21 patients had bladder injury and one patient had no bladder injury. CT cystography demonstrated a sensitivity of 100.0% (95% CI, 83.9–100.0%) and a PPV of 95.5% (95% CI, 77.2–99.9%), with an overall diagnostic accuracy of 95.5% (95% CI, 77.2–99.9%). Specificity and NPV could not be reliably estimated because there were no CT-negative cases in the study population. For individual CT findings, bladder wall discontinuity showed a sensitivity of 100.0% and specificity of 100.0%, although the corresponding confidence intervals were wide because of the small number of reference-negative cases. Intraperitoneal contrast extravasation had a sensitivity of 76.2% and specificity of 100.0%, whereas extraperitoneal contrast extravasation had a sensitivity of 83.3% and specificity of 100.0%.

Conclusion

In this single-center series of patients with suspected blunt bladder trauma, CT cystography demonstrated a high sensitivity and diagnostic accuracy for detecting bladder injury. Direct visualization of bladder wall discontinuity and contrast extravasation provided important diagnostic information. However, the small sample size and the absence of CT-negative reference-positive cases limited the precision of specificity and negative predictive value estimates.

Keywords: bladder injury; blunt abdominal trauma; computed tomography; CT cystography; bladder rupture; diagnostic accuracy

Date of Submission: 06-10-2026

Date of Acceptance: 16-10-2026

I. Introduction

Bladder injury is an uncommon but clinically significant consequence of abdominal and pelvic trauma. It accounts for approximately 2%–4% of abdominal injuries requiring surgical intervention [6]. Bladder rupture is classified according to its relationship to the peritoneal cavity, with extraperitoneal rupture accounting for approximately 60% of cases, intraperitoneal rupture for 30%, and combined intraperitoneal and extraperitoneal rupture for approximately 10% [19]. Bladder injuries may occur as isolated lesions or in association with pelvic fractures and injuries to other intra-abdominal or genitourinary organs. Accurate and timely diagnosis is important

because the type and extent of bladder injury directly influence the choice between conservative and surgical management.

Bladder injury may be overlooked during the initial assessment of patients with multiple trauma, particularly when clinical attention is focused on immediately life-threatening conditions such as traumatic brain or spinal cord injury and severe hemorrhage from solid-organ injuries. Delayed or missed diagnosis may increase the risk of complications, including urinary tract infection, pelvic abscess, urinary incontinence, and fistula formation. In patients with multiple traumatic injuries, bladder injury may occur as part of a complex pattern of associated organ damage, and reported mortality rates may reach 10%–22% [7].

Several imaging modalities have been used to evaluate suspected bladder injury, including plain abdominal radiography, ultrasonography, intravenous urography, conventional retrograde cystography, and computed tomography (CT) cystography. Plain abdominal radiography has limited value for directly diagnosing bladder rupture, although it may demonstrate associated findings such as pelvic fractures or free intraperitoneal gas. Conventional cystography has historically been an established diagnostic technique and can provide direct evidence of contrast extravasation from a ruptured bladder. However, it provides limited information regarding associated intra-abdominal and pelvic injuries. False-negative findings may also occur in patients with small bladder tears or limited contrast extravasation [14]. Ultrasonography is widely used in the initial assessment of trauma and can detect free intraperitoneal fluid as well as some solid-organ injuries. However, its diagnostic performance for deep pelvic structures may be limited, particularly in patients who are uncooperative or have substantial bowel gas. Retrograde bladder filling with saline or contrast material can improve the detection of bladder rupture [16], [21].

Bladder injuries are commonly classified as intraperitoneal, extraperitoneal, or combined according to the location and direction of urine or contrast extravasation. Intraperitoneal rupture typically results from disruption of the bladder dome and allows urine or contrast material to enter the peritoneal cavity. In contrast, extraperitoneal rupture is more commonly associated with injury to the bladder base or pelvic trauma, particularly pelvic fractures. Combined injuries exhibit features of both patterns. This distinction is clinically important because treatment strategies differ according to the type, location, and complexity of the rupture.

Computed tomography cystography (CTC) has increasingly become the preferred imaging technique for evaluating suspected bladder injury in patients with abdominal or pelvic trauma. CTC combines multidetector CT imaging with retrograde filling of the bladder using diluted water-soluble contrast material, allowing direct visualization of contrast extravasation and simultaneous assessment of associated injuries. Reported sensitivity and specificity for CTC in detecting bladder rupture are approximately 94.7%–100% and 100%, respectively [1], [3], [14]. In addition to demonstrating contrast extravasation, CT may identify bladder wall discontinuity, intravesical blood clots, perivesical fluid, sentinel clot, and the fat triangle sign. These findings may provide additional diagnostic information and help characterize the location and type of bladder injury.

The major advantage of CTC over conventional cystography is its ability to evaluate the bladder and the surrounding anatomical structures during the same examination. In patients with abdominal or pelvic trauma, CT can simultaneously demonstrate associated injuries involving the solid organs, bowel, pelvic bones, urinary tract, and other intra-abdominal structures. This comprehensive assessment may be particularly valuable in patients with multiple trauma, in whom bladder injury may coexist with other clinically important injuries. Nevertheless, the diagnostic performance of individual CT findings may vary according to the type and extent of bladder injury, and relatively few studies have systematically evaluated the diagnostic value of individual CT signs in relation to a definitive reference standard.

In Vietnam, several studies conducted at major trauma centers, including Viet Duc University Hospital and Cho Ray Hospital, have investigated bladder rupture, but these studies have focused primarily on clinical characteristics and surgical management, with relatively limited assessment of the role of diagnostic imaging [22], [23], [25], [26]. Evidence regarding the diagnostic performance of multidetector CT and the value of individual CT findings in the diagnosis and characterization of bladder injury remains limited, particularly in regional trauma centers.

Friendship General Hospital of Nghe An is a major referral hospital in North Central Vietnam and routinely receives patients with abdominal and pelvic trauma. Bladder injuries are encountered among these patients and are diagnosed and treated using contemporary clinical and imaging approaches. However, to date, no study at this institution has systematically evaluated the diagnostic performance of CT cystography or the diagnostic value of individual CT findings in patients with suspected bladder injury.

Previous studies have demonstrated the high diagnostic value of CT cystography for bladder injury and have also identified several ancillary CT findings that may assist in diagnosis and characterization. Morgan *et al.* [11] evaluated 157 trauma patients with hematuria who underwent CT cystography and reported a strong association between pelvic fluid and bladder rupture, suggesting that the absence of pelvic fluid could help exclude bladder injury. Similarly, Pao *et al.* [12], in a study of 54 patients with blunt abdominal trauma who underwent abdominal CT and retrograde cystography, reported that the absence of extravesical fluid and pelvic fracture had

a negative predictive value of 100% for bladder rupture. These findings suggest that indirect CT signs may provide useful information, particularly when direct visualization of the rupture site is difficult.

Subsequent studies further established the diagnostic performance of CT cystography. Chan *et al.* [1] evaluated 234 patients with blunt abdominal trauma and reported a sensitivity of 100% for CT cystography in detecting bladder rupture. In a larger series of 283 patients with bladder injury, Quagliano *et al.* [14] demonstrated that CT cystography and conventional retrograde cystography had a sensitivity of 94.7% and a specificity of 100%, with a positive predictive value of 100%. These findings supported the use of CT cystography as an accurate diagnostic technique for suspected bladder rupture, particularly in patients with concomitant abdominal or pelvic injuries.

In addition to direct contrast extravasation, several ancillary CT signs have been investigated to improve the detection and characterization of bladder rupture. Shin *et al.* [18] studied 74 patients with bladder injury and found that identification of a hematoma adjacent to the bladder and above the bladder dome could improve the accuracy of CT in diagnosing intraperitoneal bladder rupture. This localized hematoma, termed the “sentinel clot” sign, tends to occur close to the site of bladder wall disruption and may therefore provide an indirect indication of the rupture site. Gross *et al.* [5] subsequently described the “fat triangle sign” in patients with extraperitoneal bladder rupture. This sign reflects the anatomical configuration of the space of Retzius and the displacement of extraperitoneal fat by fluid, blood, or extravasated contrast material within the prevesical space.

More recent studies have continued to confirm the high diagnostic performance of CT while evaluating specific imaging findings. Ramadan *et al.* [15] reported a sensitivity of 96.88% for CT in detecting bladder injury and a sensitivity of 93.33% for identifying bladder wall disruption. Direct contrast extravasation through the rupture site demonstrated a sensitivity of 96.67%, specificity of 100%, positive predictive value of 100%, negative predictive value of 66.67%, and overall accuracy of 96.88%. In 2020, Trinci *et al.* [20] evaluated gas-enhanced CT cystography as an alternative to conventional retrograde filling with contrast material in 97 patients with bladder rupture. The authors reported a sensitivity and specificity of 100% and suggested that the technique could reduce examination time and imaging costs.

In Vietnam, several studies have also investigated the diagnostic role of imaging in traumatic bladder rupture. Tran *et al.* [25] studied patients with pelvic fractures treated between 1998 and 2000, including 26 patients with associated bladder rupture, and emphasized the diagnostic value of pressure retrograde cystography, with no false-negative cases reported. Vu [26] subsequently evaluated the diagnostic value of CT with and without retrograde bladder filling in patients with traumatic bladder rupture. The sensitivity and specificity of CT cystography with retrograde contrast filling were both 100%, whereas the sensitivity of CT without retrograde filling was only 38.5%. These findings highlighted the importance of adequate bladder distension and retrograde contrast administration when CT is used to investigate suspected bladder rupture.

Ngo [23] evaluated 62 patients with surgically treated extraperitoneal bladder rupture at Cho Ray Hospital between January 2008 and December 2013. Retrograde cystography demonstrated high diagnostic accuracy, reaching 94%. More recently, Dang [22] investigated the diagnostic value of CT cystography in 57 patients with traumatic bladder injury and reported a sensitivity of 94.5% and a specificity of 100%. The study also suggested that CT cystography could facilitate earlier diagnosis compared with conventional delayed-phase imaging.

Although these studies have established the high diagnostic value of CT cystography for traumatic bladder injury, several limitations remain. Most previous studies have focused primarily on the overall diagnostic performance of CT cystography or on direct contrast extravasation, whereas relatively few have systematically evaluated the diagnostic contribution of individual ancillary CT findings. In particular, the sentinel clot sign and fat triangle sign have received limited evaluation in clinical studies from Vietnam. Furthermore, the available Vietnamese studies have generally been conducted at major tertiary trauma centers and have focused mainly on conventional cystography, overall CT diagnostic performance, or surgical management. There remains limited evidence regarding the diagnostic value of individual CT signs in patients with traumatic bladder injury in regional referral hospitals.

Therefore, the present study was conducted at Friendship General Hospital of Nghe An to evaluate the diagnostic performance of CT cystography in traumatic bladder injury and, importantly, to investigate the diagnostic value of selected direct and indirect CT findings, including contrast extravasation, bladder wall disruption, perivesical fluid, the sentinel clot sign, and the fat triangle sign. By assessing these findings against operative or cystoscopic findings as the reference standard, this study aimed to provide a more comprehensive evaluation of the role of multidetector CT in the diagnosis and characterization of traumatic bladder rupture.

II. Materials and Methods

2.1. Study design and setting

This was a cross-sectional descriptive study combining retrospective and prospective data collection. The study was conducted at the Departments of Radiology and Urology, Friendship General Hospital of Nghe An,

Vietnam. The study period was from June 2020 to June 2022. A total of 22 patients who met the predefined eligibility criteria were included using convenience sampling.

2.2. Patient selection

Patients were eligible if they had blunt abdominal trauma with clinical or laboratory findings suggestive of bladder injury, underwent multidetector CT with retrograde CT cystography at Friendship General Hospital of Nghe An, and subsequently underwent cystoscopy or abdominal surgery. Complete clinical records and relevant imaging and treatment information were required.

Patients were excluded if they had previously undergone surgery for traumatic bladder injury at another hospital, penetrating bladder trauma, pathological bladder rupture, iatrogenic bladder injury related to surgery or procedures, or inadequate CT examinations or examinations performed with an inappropriate imaging protocol.

2.3. CT acquisition protocol

All patients underwent CT examination with a Foley catheter inserted and clamped before imaging. Patients were positioned supine with their arms above the head and were instructed to hold their breath during image acquisition.

Routine abdominopelvic CT was performed before and after intravenous administration of water-soluble iodinated contrast material. Images were acquired from the diaphragmatic domes to the pubic symphysis with a slice thickness of 3 mm. Multiplanar reformations were generated using thin-section images with a reconstruction thickness of 0.69 mm. The tube voltage was 120 kV and the tube current-time product was 350 mAs.

Xenetic contrast medium at a concentration of 350 mg iodine/mL was administered intravenously at a dose of 1.5–2.0 mL/kg and an injection rate of 2.5–3.0 mL/s. Arterial-phase imaging was obtained approximately 25–30 seconds after injection, followed by venous-phase imaging at 60–70 seconds. In patients with suspected renal injury, an additional delayed phase was obtained 3–5 minutes after injection to assess the urinary collecting system.

Retrograde CT cystography was then performed through the Foley catheter. Approximately 250–350 mL of diluted water-soluble contrast medium in normal saline was instilled to achieve a contrast concentration of approximately 3–5%. Instillation was stopped when no further fluid could be introduced or when the patient developed significant pain or discomfort. The Foley catheter was then clamped to maintain bladder distension. Pelvic CT was obtained from above the iliac crest to the level of the lesser trochanters.

Contrast extravasation from the bladder into the intraperitoneal, extraperitoneal, perineal, or inguinal/scrotal spaces was assessed.

2.4. Image interpretation

CT examinations were reviewed by two radiologists from the Department of Radiology, each with more than five years of experience. Images were evaluated using the CT workstations and the Carestream Vue Motion PACS. The radiologists recorded the imaging findings using a standardized research form.

The evaluated CT findings included intravesical blood clot, bladder wall contusion, bladder wall discontinuity, perivesical fluid or hematoma, the sentinel clot sign, the fat triangle sign, intraperitoneal and extraperitoneal contrast extravasation, free intraperitoneal fluid, free intraperitoneal gas, pelvic fractures, and associated visceral injuries.

Bladder wall contusion was defined as focal or diffuse bladder wall thickening greater than 3 mm with homogeneous or heterogeneous attenuation before contrast administration and heterogeneous enhancement after contrast administration. Bladder wall discontinuity was defined as a focal interruption of the bladder wall, which could contain blood, clot, or contrast material. The sentinel clot sign was defined as a hyperattenuating clot adjacent to the site of bladder injury. The fat triangle sign represented anterior displacement of extraperitoneal fat by fluid or blood within the retropubic space.

2.5. Reference standard and classification of bladder injury

The reference standard was based on findings from cystoscopy or abdominal surgery. Bladder injuries were classified according to the Sandler classification into bladder contusion, intraperitoneal rupture, interstitial injury, extraperitoneal rupture, and combined intraperitoneal and extraperitoneal rupture.

2.6. Study variables

Demographic variables included age, sex, and mechanism of trauma. Clinical variables included suprapubic pain, gross hematuria, dysuria, loss of urinary urge, lower abdominal bruising or abrasions, abdominal wall reaction, pelvic compression pain, and polytrauma.

Associated injuries recorded from the clinical and imaging records included injuries to the liver, spleen, kidney, pancreas, small bowel, colon, urethra, genital organs, other intra-abdominal organs, and other extra-abdominal structures. Pelvic fractures were also recorded.

The primary imaging variables were the predefined CT findings described above. Diagnostic performance was assessed using sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy. Associations between selected CT findings and operative or cystoscopic findings were also explored.

2.7. Statistical analysis

Data were processed using SPSS version 20.0. Continuous variables were summarized using means, whereas categorical variables were expressed as frequencies and percentages. Associations between categorical variables were assessed using the chi-square test or Fisher's exact test, as appropriate. A two-sided p value <0.05 was considered statistically significant.

Diagnostic performance was evaluated using 2×2 contingency tables, with operative or cystoscopic findings used as the reference standard. Sensitivity, specificity, PPV, NPV, and accuracy were calculated according to standard definitions.

For the present manuscript, 95% confidence intervals for diagnostic proportions were additionally calculated using the exact binomial method because of the small sample size. Estimates based on very small denominators were interpreted cautiously.

2.8. Ethical considerations

The study protocol was reviewed and approved by the Scientific Council of Friendship General Hospital of Nghe An. Study variables were collected objectively and scientifically, and information obtained from medical records was kept confidential and used solely for research purposes.

IV. Results

4.1. Patient characteristics

A total of 22 patients were included in the study. The patients ranged in age from 16 to 67 years, with a mean age of 43 years. The largest age group was 18–40 years, accounting for 50.0% of the study population. The age distribution is presented in Table 1.

There were 20 men (90.9%) and 2 women (9.1%), corresponding to a male-to-female ratio of 10:1. Traffic accidents were the predominant mechanism of injury, accounting for 77.3% of cases, followed by occupational accidents (13.6%) and domestic accidents (9.1%).

Table 1. Demographic and clinical characteristics of the study population

Characteristic	n	%
Age, years		
Mean	43	
43	16-67	
Range	11	50.0
Sex		
Male	20	90.9
Female	2	9.1
Mechanism of injury		
Road traffic accident	17	77.6
Occupational accident	3	13.6
Domestic accident	2	9.1
Clinical findings		
Gross hematuria	22	100.0
Suprapubic pain	21	95.5
Abdominal wall reaction	17	77.3
Lower abdominal bruising or abrasion	13	59.0
Loss of urinary urge	3	13.6
Dysuria	3	13.6
Positive pelvic compression test	3	13.6
Polytrauma	11	50.0

4.2. Clinical findings

Gross hematuria was present in all 22 patients (100.0%), while suprapubic pain was reported in 21 patients (95.5%). Abdominal wall reaction was observed in 17 patients (77.3%), and lower abdominal bruising or abrasions were present in 13 patients (59.0%). Loss of urinary urge, dysuria, and positive pelvic compression pain were each observed in 3 patients (13.6%). Eleven patients (50.0%) presented with polytrauma. The clinical findings of the study population are summarized in Table 1.

4.3. Associated injuries and bladder injury classification

Associated injuries included small-bowel injury in 3 patients (13.6%), colonic injury in 2 (9.1%), splenic injury in 2 (9.1%), hepatic injury in 1 (4.5%), and renal injury in 1 (4.5%). Three patients had other intra-abdominal injuries. No urethral or genital-organ injuries were recorded, as illustrated in Talbe 2.

According to operative or cystoscopic findings, 21 of the 22 patients had bladder injury. Intraperitoneal rupture was the most common injury pattern, accounting for 15 cases (68.2%), followed by extraperitoneal rupture in 4 cases (18.2%), combined injury in 2 cases (9.1%), and bladder contusion in 1 case (4.5%). No interstitial injuries were identified.

Table 2. Associated injuries and CT findings

Finding	n	%
Associated injuries		
Small-bowel injury	3	13.6
Splenic injury	2	9.1
Colonic injury	2	9.1
Hepatic injury	1	4.5
Renal injury	1	4.5
Other intra-abdominal injuries	3	13.6
Pelvic fracture	3	13.6
CT findings		
Free intraperitoneal fluid	22	100.0
Bladder wall discontinuity	21	95.5
Intraperitoneal contrast extravasation	17	77.3
Sentinel clot sign	16	72.7
Intravesical clot	14	63.6
Perivesical fluid	10	45.5
Bladder wall contusion	7	31.8
Extraperitoneal contrast extravasation	4	18.2
Fat triangle sign	3	13.6
Free intraperitoneal gas	2	9.1

4.4. CT findings

The most frequently observed CT findings were free intraperitoneal fluid, present in 22 patients (100.0%), and bladder wall discontinuity, present in 21 patients (95.5%). Intraperitoneal contrast extravasation was observed in 17 patients (77.3%), whereas extraperitoneal contrast extravasation was observed in 4 patients (18.2%).

The sentinel clot sign was identified in 16 patients (72.7%), intravesical clot in 14 (63.6%), perivesical fluid in 10 (45.5%), bladder wall contusion in 7 (31.8%), and the fat triangle sign in 3 (13.6%). Free intraperitoneal gas was observed in 2 patients; the original study table reports this as 0.9%, although 2/22 corresponds to 9.1%.

4.5. Diagnostic performance of individual CT findings

The diagnostic performance of individual CT findings is summarized in Table 3. Overall, several CT findings demonstrated high sensitivity and diagnostic accuracy for bladder injury, although the precision of some estimates was limited by the small number of reference-negative cases.

Intravesical clot demonstrated a sensitivity of 100.0%, specificity of 88.9%, positive predictive value (PPV) of 92.9%, negative predictive value (NPV) of 100.0%, and overall accuracy of 95.5%. Bladder wall contusion showed similarly high sensitivity (100.0%) and accuracy (95.5%), with a specificity of 75.0%, PPV of 94.7%, and NPV of 100.0%. Bladder wall discontinuity demonstrated perfect diagnostic performance in this study, with 100.0% sensitivity, specificity, PPV, NPV, and accuracy. However, these estimates should be interpreted with caution because specificity and NPV were each based on only one reference-negative patient, resulting in very wide confidence intervals.

Perivesical fluid demonstrated a sensitivity of 80.0%, specificity of 83.3%, PPV of 80.0%, NPV of 83.3%, and accuracy of 81.8% for the overall detection of bladder injury. When specifically evaluated for the detection of extraperitoneal rupture, perivesical fluid showed a sensitivity of 100.0%, specificity of 61.1%, PPV of 36.4%, NPV of 100.0%, and accuracy of 68.2%. Thus, although the absence of perivesical fluid was useful for excluding extraperitoneal rupture in this cohort, its presence had limited specificity for this injury pattern.

The sentinel clot sign demonstrated a sensitivity of 85.7%, specificity of 50.0%, PPV of 75.0%, NPV of 66.7%, and accuracy of 72.7% when compared with operative or cystoscopic evidence of perivesical hematoma. The fat triangle sign was observed in three of the four patients with extraperitoneal rupture, corresponding to a sensitivity of 75.0% and a PPV of 100.0%. Specificity could not be reliably estimated because no reference-negative patient was available for this specific analysis.

Direct contrast extravasation showed high diagnostic specificity. Intraperitoneal contrast extravasation had a sensitivity of 76.2%, specificity of 100.0%, PPV of 100.0%, NPV of 16.7%, and accuracy of 77.3%.

Extraperitoneal contrast extravasation demonstrated a sensitivity of 83.3%, specificity of 100.0%, PPV of 100.0%, NPV of 94.1%, and accuracy of 95.5%.

Free intraperitoneal fluid was identified in all 21 patients with bladder injury and also in the single reference-negative patient. Consequently, its sensitivity was 100.0%, whereas the observed specificity was 0%. Because only one reference-negative patient was available, this specificity estimate was highly unstable and should not be interpreted as evidence of poor diagnostic performance. Rather, the finding indicates that free intraperitoneal fluid was common in this trauma population but was not specific for bladder injury.

Table 3. Diagnostic performance of selected CT findings

CT finding / diagnostic target	Sensitivity, % (95% CI)	Specificity, % (95% CI)	PPV, % (95% CI)	NPV, % (95% CI)	Accuracy, % (95% CI)
Intravesical clot / bladder injury	100.0 (75.3–100)	88.9 (51.8–99.7)	92.9 (66.1–99.8)	100.0 (63.1–100)	95.5 (77.2–99.9)
Bladder wall contusion / bladder injury	100.0 (81.5–100)	75.0 (19.4–99.4)	94.7 (74.0–99.9)	100.0 (29.2–100)	95.5 (77.2–99.9)
Bladder wall discontinuity / bladder injury	100.0 (83.9–100)	100.0 (2.5–100)	100.0 (83.9–100)	100.0 (2.5–100)	100.0 (84.6–100)
Perivesical fluid / bladder injury	80.0 (44.4–97.5)	83.3 (51.6–97.9)	80.0 (44.4–97.5)	83.3 (51.6–97.9)	81.8 (59.7–94.8)
Perivesical fluid / extraperitoneal rupture	100.0 (39.8–100)	61.1 (35.7–82.7)	36.4 (10.9–69.2)	100.0 (71.5–100)	68.2 (45.1–86.1)
Sentinel clot sign / perivesical hematoma	85.7 (57.2–98.2)	50.0 (15.7–84.3)	75.0 (47.6–92.7)	66.7 (22.3–95.7)	72.7 (49.8–89.3)
Fat triangle sign / extraperitoneal rupture	75.0 (19.4–99.4)	Not estimable	100.0 (29.2–100)	0.0 (0–97.5)	75.0 (19.4–99.4)
Intraperitoneal contrast extravasation / bladder injury	76.2 (52.8–91.8)	100.0 (2.5–100)	100.0 (79.4–100)	16.7 (0.4–64.1)	77.3 (54.6–92.2)
Extraperitoneal contrast extravasation / extraperitoneal rupture	83.3 (35.9–99.6)	100.0 (79.4–100)	100.0 (47.8–100)	94.1 (71.3–99.9)	95.5 (77.2–99.9)
Overall CT cystography / bladder injury	100.0 (83.9–100)	0.0 (0–97.5)	95.5 (77.2–99.9)	Not estimable	95.5 (77.2–99.9)

Note. PPV, positive predictive value; NPV, negative predictive value; CI, confidence interval. Confidence intervals are exact binomial 95% CIs. Estimates with very small denominators are imprecise. Overall CT cystography specificity is 0% based on only one reference-standard-negative patient; NPV is undefined because no CT-negative examinations occurred. The fat triangle comparison had no reference-negative cases, so specificity could not be calculated.

4.6. Diagnostic performance of CT cystography

CT cystography was interpreted as positive for bladder injury in all 22 patients. According to the operative or cystoscopic reference standard, 21 patients had confirmed bladder injury, whereas 1 patient had no evidence of bladder injury.

CT cystography therefore demonstrated a sensitivity of 100.0% (95% CI, 83.9–100.0%), a positive predictive value (PPV) of 95.5% (95% CI, 77.2–99.9%), and an overall diagnostic accuracy of 95.5% (95% CI, 77.2–99.9%). No false-negative CT cystography examinations were observed in the study population.

Because no patient with confirmed bladder injury had a negative CT cystography result, the negative predictive value (NPV) could not be estimated. The observed specificity was 0%, reflecting the fact that the only reference-negative patient was classified as positive on CT cystography. However, this estimate is based on a single reference-negative case and therefore has extremely limited precision. The diagnostic performance estimates should consequently be interpreted in the context of the small and highly selected study population.

4.7. Classification of bladder injury

The agreement between CT-based classification and the operative or cystoscopic reference standard is presented in Table 4. Overall, CT correctly classified 20 of 22 patients, corresponding to an overall classification accuracy of 90.9%.

Complete agreement was observed for bladder contusion and intraperitoneal rupture, with all corresponding cases correctly classified (1/1 and 15/15, respectively). Extraperitoneal rupture was correctly classified in 3 of 4 cases (75.0%), whereas combined intraperitoneal and extraperitoneal rupture was correctly classified in 1 of 2 cases (50.0%).

These findings indicate that CT classification showed high overall agreement with the reference standard in this cohort, particularly for intraperitoneal rupture. However, the estimates for extraperitoneal and combined injuries should be interpreted cautiously because of the small number of cases in these subgroups.

Table 4. Agreement between CT classification and operative or cystoscopic findings

CT classification	Correctly classified, n / total	Agreement, %
Bladder contusion	1/1	100.0
Intraperitoneal rupture	15/15	100.0
Extraperitoneal rupture	3/4	75.0
Combined intraperitoneal and extraperitoneal rupture	1/2	50.0
Overall	20/22	90.9

V. Discussion

This study evaluated the CT findings and diagnostic performance of CT cystography in 22 patients with suspected traumatic bladder injury. Gross hematuria and suprapubic pain were the most frequent clinical findings, occurring in 100.0% and 95.5% of patients, respectively (Table 1). Bladder wall discontinuity was the most frequent direct bladder abnormality, identified in 21 patients (95.5%), while intraperitoneal contrast extravasation was identified in 17 patients (77.3%) (Table 2). Compared with operative or cystoscopic findings, CT cystography had a sensitivity of 100.0%, a PPV of 95.5%, and an accuracy of 95.5% (Table 3). CT correctly classified the pattern of bladder injury in 20 of 22 patients (90.9%) (Table 4).

5.1. Clinical characteristics

The demographic characteristics of our cohort were consistent with the clinical context of traumatic bladder injury. Most patients were men (90.9%), and the mean age was 43 years. Road traffic accidents accounted for 77.3% of the injuries (Table 1). The predominance of road traffic trauma has also been reported in previous studies of traumatic bladder injury [5], [6], [15].

The age distribution in our study was generally comparable to that reported in both international and Vietnamese studies, although differences in the study populations and inclusion criteria resulted in some variation in the reported mean ages. Deck *et al.* [3] reported a mean age of 32 years, with an age range of 6–72 years, whereas Chan *et al.* [1] reported a mean age of 42.3 years, with a wider range of 4–93 years. In the present study, patients ranged in age from 16 to 67 years, with a mean age of 43 years. The 18–40-year age group was the most represented, accounting for 50.0% of the cohort.

Similar patterns have been reported in Vietnamese studies. Ngo Ngoc Tuan reported an age range of 14–53 years, with a mean age of 33.74 years, and identified patients aged 21–50 years as the most commonly affected group. Nguyen *et al.* [24] reported a mean age of 34.5 years, with ages ranging from 11 to 68 years; patients younger than 30 years accounted for the largest proportion (46.3%). Vu [26] reported a mean age of 32.67 years, with a range of 14–52 years, and found that patients aged 20–39 years were the most frequently affected. Dang [22] reported an age range of 16–67 years, with a mean age of 35.9 years, and the 20–39-year age group accounted for the largest proportion (47.4%).

Gross hematuria was present in all patients in the present study, while suprapubic pain occurred in 95.5% (Table 1). Visible hematuria is a recognized clinical indicator of bladder injury and is an important trigger for cystographic evaluation in appropriate trauma patients. Current urological trauma guidelines identify visible hematuria, particularly when associated with pelvic fracture or a concerning mechanism, as an indication for retrograde cystography [2]. The high frequency of hematuria in our study is therefore consistent with the established clinical presentation of traumatic bladder injury.

Gross hematuria is particularly common in bladder trauma because disruption of the highly vascularized bladder wall can result in bleeding into the urinary tract. Previous studies have reported similarly high frequencies of visible hematuria among patients with confirmed bladder injury. Deck *et al.* [3] reported gross hematuria in 89% of 44 patients with traumatic bladder rupture. Trinci *et al.* [20] observed gross hematuria in 84 of 97 patients (86.6%) with bladder rupture. Ramadan *et al.* [15] also reported gross hematuria in 29 of 32 patients (90.6%) with traumatic bladder injury. In comparison, gross hematuria was observed in 100.0% of patients with surgically confirmed bladder rupture in our study.

Although the frequency observed in our cohort was somewhat higher than that reported in these previous studies, the overall findings support the consistent association between gross hematuria and traumatic bladder injury. The slightly higher proportion in our study may be related to the small sample size and the selected nature of the study population. In particular, all patients included in the present study had clinical or imaging findings

sufficiently suggestive of bladder injury to undergo CT cystography and subsequent operative or cystoscopic assessment.

Suprapubic pain was also highly prevalent in our cohort, occurring in 95.5% of patients. This finding is clinically compatible with bladder injury, particularly when accompanied by hematuria, although suprapubic pain is not specific to bladder rupture and may also occur with pelvic fractures or other lower abdominal and pelvic injuries. Similarly, abdominal wall reaction and lower abdominal bruising or abrasions were observed in a substantial proportion of patients, reflecting the high-energy mechanisms underlying many traumatic bladder injuries.

Importantly, the high prevalence of gross hematuria in this study should not be interpreted as an estimate of the sensitivity or specificity of hematuria for bladder injury in the general trauma population. All participants were selected from patients with suspected bladder injury and subsequently underwent CT cystography and operative or cystoscopic evaluation. This spectrum and selection bias may have increased the observed frequency of characteristic clinical findings. Nevertheless, within this selected population, the presence of gross hematuria was a consistent clinical feature and supports its role as an important trigger for further diagnostic evaluation of suspected bladder injury.

5.2. CT findings of traumatic bladder injury

The most frequent CT findings were free intraperitoneal fluid, bladder wall discontinuity, intraperitoneal contrast extravasation, and the sentinel clot sign (Table 2). The combination of direct and indirect findings is clinically relevant because bladder injury may coexist with multiple abdominal or pelvic injuries.

Bladder wall discontinuity was identified in 21 of 22 patients and demonstrated 100.0% sensitivity and 100.0% specificity in this cohort (Table 3). Previous work has demonstrated the usefulness of multidetector CT with multiplanar reformations in identifying the site and pattern of bladder rupture. Chan *et al.*, in a series of 234 patients, reported 100% sensitivity and specificity for CT cystography in the diagnosis of bladder rupture and emphasized the value of sagittal and coronal reformations [1]. The present result is therefore compatible with the high diagnostic performance reported in larger series.

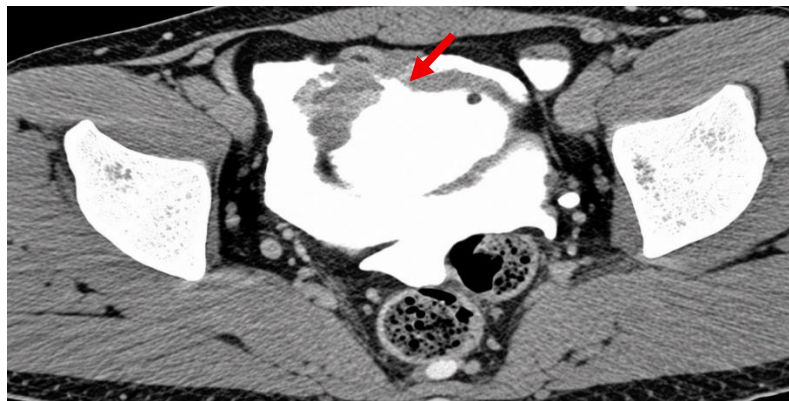


Figure 1. Bladder wall contusion adjacent to a bladder rupture.

Nevertheless, the 100% specificity observed in our study should be interpreted cautiously because only one patient was negative according to the reference standard. Thus, the confidence interval around the estimate is necessarily very wide. The result demonstrates the performance observed in this cohort but does not establish a population-level specificity of 100%.

Intravesical blood clot was identified in 14 patients (63.6%) and had a sensitivity of 100.0%, specificity of 88.9%, and accuracy of 95.5% (Table 3). Figure 2 illustrates a large intravesical clot associated with subsequent contrast extravasation. Previous studies have also reported intravesical clot as a frequent CT finding in traumatic bladder rupture [1]. Because intravesical blood clot may reflect bleeding rather than direct bladder wall disruption, it should be interpreted as a supportive rather than an isolated diagnostic sign.

Bladder wall contusion was identified in 7 patients in the descriptive CT assessment (Table 2). In the diagnostic comparison, the corresponding analysis showed 18 reference-positive cases and yielded a sensitivity of 100.0% and specificity of 75.0% (Table 3). Figure 1 demonstrates bladder wall contusion adjacent to a rupture. The lower specificity compared with bladder wall discontinuity indicates that wall thickening or contusion is less specific for established bladder rupture.

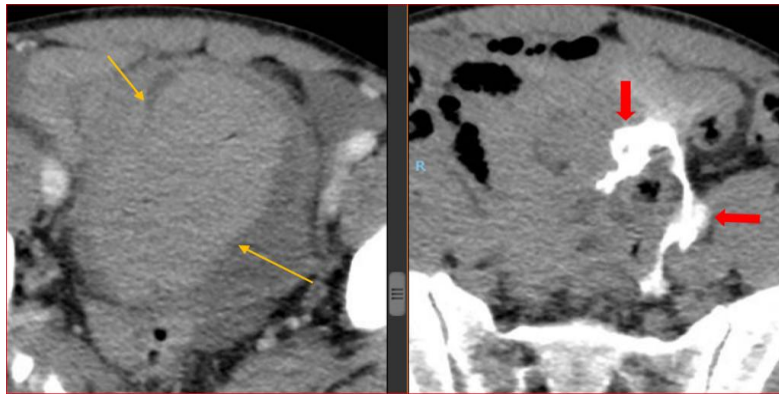


Figure 2. Intravesical blood clot and subsequent intraperitoneal contrast extravasation on CT cystography.

5.3. Contrast extravasation and CT cystography

Contrast extravasation is the principal direct imaging sign assessed by retrograde CT cystography. In our study, intraperitoneal contrast extravasation was observed in 17 patients and had a sensitivity of 76.2% and specificity of 100.0% for the corresponding reference-standard comparison. Extraperitoneal contrast extravasation was observed in 4 patients in the descriptive analysis and had a sensitivity of 83.3% and specificity of 100.0% in the diagnostic comparison (Table 3). Figure 3 demonstrates intraperitoneal extravasation, whereas Figure 4 demonstrates extraperitoneal extravasation.

The lower sensitivity of individual extravasation patterns compared with the overall detection of bladder injury is clinically relevant. Absence of a particular pattern of extravasation does not necessarily exclude bladder injury, especially when other direct or indirect findings are present. Conversely, when contrast extravasation is demonstrated, its distribution can provide important information about the type of bladder injury.

The technical quality of bladder distension is particularly important. Current EAU guidance recommends active retrograde filling of the bladder with dilute contrast and a minimum instillation volume of approximately 300–350 mL; passive filling of the bladder with intravenously administered contrast during the excretory phase is considered insufficient to exclude bladder injury [2]. Adequate bladder distension is essential because insufficient filling may fail to adequately distend the bladder wall and may consequently reduce the conspicuity of small tears or limited contrast extravasation.

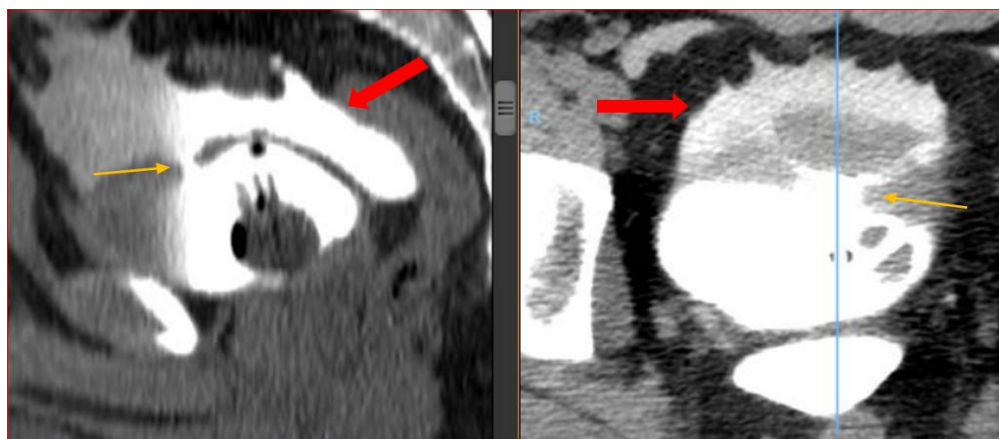


Figure 3. Bladder wall discontinuity with intraperitoneal contrast extravasation.

Mee *et al.* [10] recommended retrograde bladder filling with a minimum volume of approximately 250–300 mL and emphasized that adequate bladder distension, together with the absence or presence of contrast extravasation, is important for accurate assessment of bladder integrity. These recommendations are broadly consistent with the technical approach used in the present study.

In our study, the bladder was actively filled retrogradely with approximately 250–350 mL of diluted water-soluble contrast material. Instillation was stopped according to patient tolerance and the ability to introduce additional contrast. This protocol provided adequate bladder distension in the study population and allowed direct assessment of contrast extravasation from the bladder. The use of retrograde filling in all patients may have contributed to the high sensitivity of CT cystography observed in our cohort, particularly by improving visualization of small or otherwise inconspicuous bladder wall defects.

The findings also emphasize the importance of distinguishing CT cystography from routine contrast-enhanced CT performed during the excretory phase. Although routine CT may demonstrate indirect signs suggestive of bladder injury, such as perivesical fluid or pelvic hematoma, adequate retrograde bladder distension is necessary when the clinical objective is to reliably assess bladder integrity. In patients with suspected bladder injury, a standardized CT cystography protocol may therefore improve diagnostic confidence and reduce the risk of false-negative examinations.

5.4. Overall diagnostic performance of CT cystography

In the present study, CT cystography was interpreted as positive in all 22 patients. Operative or cystoscopic assessment confirmed bladder injury in 21 patients and found no bladder injury in one patient (Table 3). Accordingly, the observed sensitivity was 100.0%, PPV was 95.5%, and accuracy was 95.5%.

These findings are broadly consistent with previous studies reporting high diagnostic performance of CT cystography. Chan *et al.* reported 100% sensitivity and specificity in 234 examinations [1]. Quagliano *et al.* also found CT cystography to be highly accurate compared with conventional retrograde cystography [14]. A review by Fouladi *et al.* described CT cystography as an important imaging technique for suspected bladder injury because it can be performed together with trauma CT and provides information about associated injuries [4].

The results should nevertheless be interpreted differently from those larger studies because of the structure of our sample. Only one patient was negative according to the reference standard, and no CT cystography examination was interpreted as negative. Consequently, the observed specificity was 0% because the single reference-negative patient had a positive CT cystography result, whereas NPV could not be calculated because there were no CT-negative examinations (Table 3). This does not imply that CT cystography has intrinsically poor specificity. Rather, it reflects the highly selected study population and the absence of an adequate number of reference-negative patients.

This distinction is important because the original study reported a PPV of 100%. Recalculation from the 2×2 table gives 21 true-positive and 1 false-positive examination, corresponding to a PPV of 95.5% (Table 3). The corrected value should be used throughout the manuscript.

5.5. Perivesical fluid and free intraperitoneal fluid

Perivesical fluid was identified in 10 patients (45.5%) and demonstrated a sensitivity of 80.0%, specificity of 83.3%, and accuracy of 81.8% for bladder injury (Table 3). When evaluated specifically for extraperitoneal rupture, perivesical fluid had a sensitivity of 100.0% but a specificity of 61.1%. Figure 5 illustrates perivesical fluid.

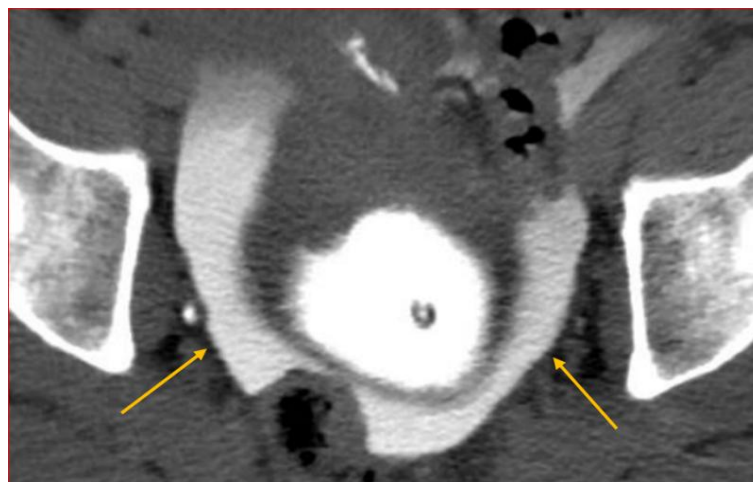


Figure 5. *Perivesical fluid collection.*

These findings indicate that perivesical fluid is a useful supportive sign but is not sufficiently specific to establish bladder rupture or its extraperitoneal pattern in isolation. Blood or fluid in the perivesical space may result from several mechanisms of pelvic trauma.

Free intraperitoneal fluid was frequently observed. Figure 6 illustrates a case in which free intraperitoneal fluid prompted further evaluation with retrograde CT cystography, which demonstrated contrast extravasation. In the diagnostic contingency table, free intraperitoneal fluid was present in 21 reference-positive and 1 reference-negative patient (Table 3). Therefore, although the sensitivity was 100%, the observed specificity for the entire cohort was 0%. The original report's statement of 100% specificity should not be retained because it was based on a restricted subgroup rather than the complete 2×2 table.

The presence of free intraperitoneal fluid should also be interpreted in relation to associated visceral injury. In the present study, several patients had associated abdominal injuries (Table 2), providing alternative potential sources of intraperitoneal fluid. Thus, free fluid alone cannot be regarded as a specific sign of intraperitoneal bladder rupture.

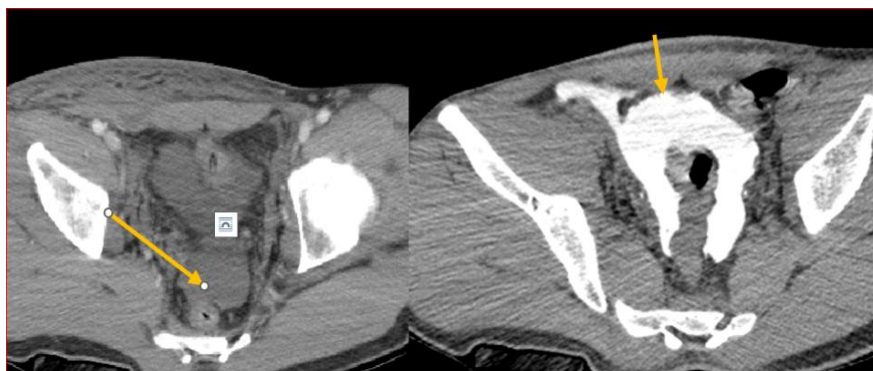


Figure 6. Free intraperitoneal fluid with bladder rupture demonstrated by retrograde CT cystography.

5.6. Sentinel clot sign

The sentinel clot sign was identified in 16 of 22 patients (72.7%) in the present study. When compared with perivesical hematoma documented at operative or cystoscopic assessment, the sign showed a sensitivity of 85.7%, specificity of 50.0%, and overall accuracy of 72.7% (Table 3). These findings indicate that the sentinel clot sign may provide useful supportive information for localizing the site of bladder injury, although its diagnostic performance was not sufficient for use as an isolated criterion.

The sentinel clot sign refers to a focal area of relatively high-attenuation blood, typically measuring approximately 60–70 HU, located adjacent to the site of visceral injury. In traumatic bladder injury, identification of a localized clot adjacent to the bladder wall, particularly near the bladder dome, may suggest the site of rupture and may be especially helpful in patients with gross hematuria. Shin *et al.* reported the sentinel clot sign in 16 of 20 patients (80%) with intraperitoneal bladder rupture, compared with 4 of 54 patients (7%) without intraperitoneal rupture ($p < 0.001$) [36]. Their findings support the role of the sign as a localizing feature, particularly for intraperitoneal bladder rupture.

Our findings were broadly consistent with those of Shin *et al.* [18], particularly with respect to the relatively frequent occurrence of the sign in patients with intraperitoneal bladder rupture. However, the specificity observed in our study was lower. Several factors may explain this difference, including differences in patient selection, sample size, reference definitions, and the outcome used for comparison. In particular, our analysis evaluated the sentinel clot sign against the presence of perivesical hematoma at operative or cystoscopic assessment, rather than specifically against intraperitoneal bladder rupture. Therefore, the two analyses do not represent identical diagnostic comparisons.

The relatively high sensitivity observed in our study suggests that the sentinel clot sign may be useful as an ancillary finding when evaluating patients with suspected bladder injury. Nevertheless, its limited specificity indicates that the sign should not be interpreted as a stand-alone diagnostic criterion. Instead, it should be integrated with the location and morphology of the bladder wall defect, the distribution of perivesical or intraperitoneal fluid, and, when bladder rupture is suspected, direct assessment by retrograde CT cystography. The findings in the present study also suggest that the sign may be particularly informative for identifying a probable site of injury and directing attention to the bladder dome or adjacent perivesical tissues. The apparently high proportion of the sign in some injury subgroups should be interpreted cautiously because of the very small number of patients in these categories.

5.7. Fat triangle sign

The fat triangle sign was observed in 3 of 4 patients with extraperitoneal bladder rupture, corresponding to a sensitivity of 75.0% and a PPV of 100.0% (Table 3). Figure 4 demonstrates extraperitoneal contrast extravasation associated with this sign.

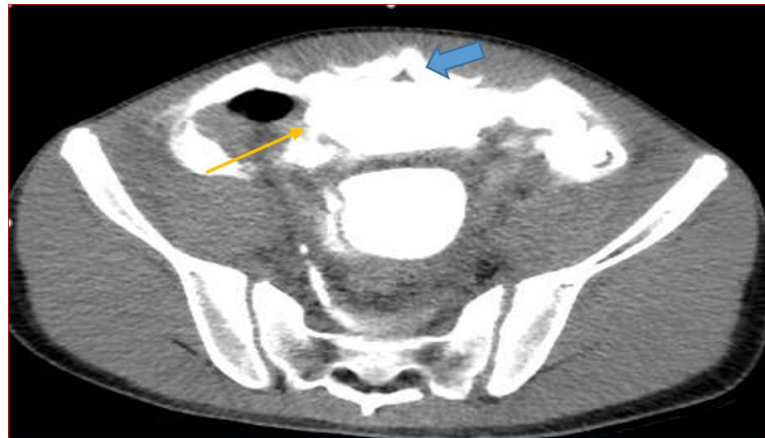


Figure 4. Extraperitoneal contrast extravasation with the fat triangle sign.

The sign was originally described by Gross *et al.* [5] as a potential imaging feature of extraperitoneal bladder rupture related to displacement of pelvic fat by fluid or blood within the extraperitoneal spaces. Our finding is compatible with the proposed role of the sign as a supportive indicator of extraperitoneal injury.

However, specificity could not be estimated in our study because all four patients included in this comparison had extraperitoneal rupture and there were no reference-negative cases (Table 3). The finding should therefore not be described as having 100% specificity or as diagnostic on its own. The small denominator also results in a very wide confidence interval for sensitivity.

5.8. Associated injuries

Associated injuries were relatively common in the present cohort and included small-bowel, colonic, splenic, hepatic, renal, diaphragmatic, spinal, and extremity injuries, as well as injuries involving the prostate and ovary (Table 2). Three patients (13.6%) had associated pelvic fractures. Among these patients, two had extraperitoneal bladder rupture and one had combined intraperitoneal and extraperitoneal rupture. Figure 7 demonstrates a pelvic fracture fragment adjacent to the bladder with associated perivesical fluid.

Pelvic fracture is widely recognized as an important associated injury in patients with traumatic bladder injury, particularly in cases of extraperitoneal rupture. Previous studies have reported substantially higher rates of pelvic fracture than that observed in our cohort. Trinci *et al.* reported pelvic fracture in 21 of 32 patients (65.6%) with bladder rupture [20], while Pereira *et al.* reported an incidence of 57.1% [13]. Landman *et al.* reported that approximately 60–90% of patients with bladder injury following blunt trauma have an associated pelvic fracture [9]. Similarly, Morgan *et al.* reported pelvic fracture in 75% of patients with bladder rupture [11], and Chan *et al.* reported pelvic trauma in 77.8% of their cases [1]. In a Vietnamese study, Dang Quang Hung reported pelvic trauma in 65.4% of patients with bladder injury diagnosed by CT, with an even higher proportion among patients with extraperitoneal rupture (85.7%) [22].

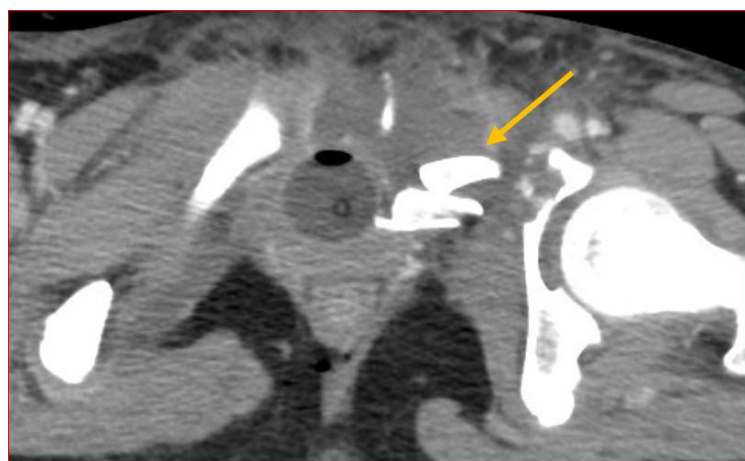


Figure 7. Pelvic fracture fragment adjacent to the bladder with associated perivesical fluid.

The substantially lower proportion of pelvic fractures in the present study, 13.6%, should therefore be interpreted cautiously. This difference may be related to the small sample size, differences in trauma mechanisms

and inclusion criteria, and variation in the spectrum of injuries represented across study populations. In addition, the present cohort was specifically composed of patients who underwent CT cystography for suspected bladder injury, rather than an unselected population of patients with major pelvic trauma. Within our cohort, pelvic fractures were observed predominantly in patients with extraperitoneal or combined rupture, which is directionally consistent with the established association between pelvic ring injury and extraperitoneal bladder rupture. However, the number of cases was too small to support reliable subgroup comparisons.

Other associated injuries were also identified on CT, including hepatic injury (n = 1), splenic injury (n = 2), renal injury (n = 1), prostatic rupture (n = 1), ovarian rupture (n = 1), diaphragmatic rupture (n = 1), small-bowel injury (n = 3), colonic injury (n = 2), spinal injury (n = 2), and extremity fractures or injuries (n = 2) (Table 2). These findings highlight the broader role of CT in the assessment of patients with blunt abdominal and pelvic trauma. In a polytrauma setting, CT performed as part of the diagnostic evaluation can assess the urinary bladder together with the abdominal viscera, bowel, retroperitoneum, and osseous structures, allowing associated injuries to be identified during the same examination.

One small-bowel injury was missed on the initial CT interpretation in our series. No free intraperitoneal gas was present, and the bowel injury was obscured by the extensive findings associated with bladder rupture. This case illustrates an important limitation of CT in the setting of complex pelvic and abdominal trauma: the presence of a conspicuous bladder injury may distract attention from less obvious associated bowel lesions. Careful systematic evaluation of the bowel and mesentery therefore remains important, even when a definite bladder rupture has already been identified.

Overall, the findings support the practical value of CT-based assessment in patients with suspected traumatic bladder injury, not only for demonstrating bladder wall disruption and contrast extravasation but also for characterizing the broader pattern of associated abdominal, pelvic, and skeletal injuries. However, the relatively low frequency of pelvic fracture and the small number of associated injuries in individual subgroups limit the generalizability of these observations.

5.9. Value of CT in the classification of bladder injury

CT correctly classified the type of bladder injury in 20 of 22 patients, corresponding to an overall classification accuracy of 90.9% (Table 4). Bladder contusion and intraperitoneal rupture were correctly classified in all corresponding cases, whereas the classification accuracy was 75.0% for extraperitoneal rupture and 50.0% for combined intraperitoneal and extraperitoneal rupture. The lower agreement observed for combined injury should be interpreted cautiously because only two patients had this injury pattern. Similarly, the estimates for individual injury categories are subject to substantial uncertainty because of the small number of cases in each subgroup.

Sandler *et al.* proposed a radiologic classification of bladder injuries based on the anatomic pattern and extent of injury [17]. This classification provides a framework for distinguishing bladder contusion from different patterns of rupture and may assist in characterizing injury severity and guiding subsequent management. In clinical practice, accurate identification of the rupture pattern is particularly relevant because intraperitoneal and extraperitoneal injuries differ in their anatomical characteristics and may require different management strategies.

The classification performance observed in the present study was broadly comparable with findings from previous CT-based studies. Chan *et al.* reported an overall correct classification rate of approximately 89%, with 100% accuracy for Sandler categories II and IV and 50% for category V [1]. Dang [22] reported an overall classification accuracy of 91.8%, with accuracies of 92.3%, 90.0%, and 50.0% for categories II, IV, and V, respectively. Vu [26] reported a lower overall accuracy of 75%, with correct classification rates of 67% for category II, 88% for category IV, and 100% for category V.

In the present study, the corresponding classification accuracies were 100% for bladder contusion and intraperitoneal rupture, 75.0% for extraperitoneal rupture, and 50.0% for combined intraperitoneal and extraperitoneal rupture. The overall accuracy of 90.9% was therefore within the range reported in previous studies. Although the observed accuracy was slightly higher than that reported by Chan *et al.* [1] and Vu [26], direct comparison should be made cautiously because of differences in study populations, sample sizes, CT protocols, reference standards, and classification procedures. The use of multidetector CT, retrograde bladder filling with contrast material, and multiplanar image reconstruction in the present study may have facilitated recognition of the anatomical extent and distribution of bladder wall disruption. However, the contribution of these technical factors cannot be established independently in this small retrospective cohort.

All injuries in the present study were classified according to the criteria proposed by Sandler *et al.* [17]. An important limitation is that the reference standard was not equally available for all injury categories. In particular, bladder contusion and other relatively minor injuries were generally managed without surgery and therefore could not be systematically verified by operative findings. Consequently, the apparent 100% classification accuracy for these categories should not be interpreted as definitive evidence of perfect diagnostic performance. Conversely, the lower accuracy observed for extraperitoneal and combined rupture may partly reflect the small number of cases rather than an inherent limitation of CT cystography.

These findings suggest that CT cystography can provide useful information not only for detecting traumatic bladder injury but also for characterizing its anatomical pattern. Accurate distinction between intraperitoneal, extraperitoneal, and combined rupture may contribute to clinical decision-making, particularly when CT findings are interpreted together with the mechanism of injury, associated pelvic or abdominal trauma, and the overall clinical condition of the patient.

5.10. Clinical and technical implications

The findings support the use of active retrograde CT cystography when traumatic bladder injury is suspected, particularly in patients with polytrauma. Early diagnosis is important for timely management and prevention of complications [18]. CT cystography provides direct visualization of contrast extravasation while simultaneously assessing the bladder, perivesical tissues, abdominal and pelvic structures, and associated visceral injuries.

The technical protocol is important for diagnostic accuracy. Delayed CT with passive accumulation of intravenously administered contrast may inadequately distend the bladder and can result in missed rupture [16]. It may also prolong the diagnostic process because imaging must be delayed until sufficient urinary contrast opacification is achieved [8]. Active retrograde bladder filling allows direct assessment of bladder integrity during the CT examination and avoids reliance on passive bladder opacification.

Multiplanar reconstruction may further improve identification of bladder wall discontinuity and localization of contrast extravasation. Nevertheless, CT findings should be interpreted together with the clinical presentation and associated injuries. Findings such as gross hematuria, pelvic trauma, perivesical fluid, intravesical clot, and bladder wall abnormalities are supportive but should not be considered diagnostic in isolation. A standardized retrograde CT cystography protocol may therefore improve diagnostic confidence while allowing simultaneous assessment of associated abdominal and pelvic injuries.

5.11. Strengths and limitations

The main strength of this study was the standardized use of multidetector CT with retrograde bladder filling, multiplanar reconstruction, and operative or cystoscopic correlation. The study also assessed both direct and indirect CT signs of bladder injury.

Several limitations should be acknowledged. First, the sample size was small and the study was conducted at a single institution. Second, the selected cohort included only one reference-standard-negative patient, limiting the precision of specificity and NPV estimates. Third, some subgroup analyses were based on very small numbers. Finally, the combination of retrospective and prospective data collection and the discrepancy in the reported study period may have introduced potential sources of bias.

5.12. Implications for future research

Future studies should use a larger prospective cohort including both patients with and without bladder injury. Such a design would provide a substantially more reliable estimate of specificity and NPV and would permit more robust assessment of individual CT signs.

Future work should also evaluate interobserver agreement between radiologists, particularly for subtle signs such as bladder wall discontinuity, sentinel clot, and the fat triangle sign. A multicenter design would further improve the generalizability of the findings.

Overall, the present study adds local evidence supporting the diagnostic role of retrograde CT cystography in suspected blunt bladder trauma, while also demonstrating the importance of interpreting diagnostic performance estimates in relation to sample composition and reference-standard verification.

VI. Conclusion

In this single-center cohort of patients with blunt abdominal trauma, CT cystography demonstrated high diagnostic performance for detecting traumatic bladder injury, with a sensitivity of 100.0% and an overall accuracy of 95.5% when compared with operative or cystoscopic findings.

Bladder wall discontinuity, intravesical clot, bladder wall contusion, and contrast extravasation provided important imaging findings for the detection and characterization of bladder injury. CT correctly classified the type of bladder injury in 90.9% of cases.

Because of the small sample size, single-center design, and the presence of only one reference-standard-negative patient, estimates of specificity and negative predictive value were highly imprecise. Larger prospective studies including patients without bladder injury are needed to validate the diagnostic performance of CT cystography and individual CT signs.

Declarations

Ethics approval and consent to participate

The study protocol was reviewed and approved by the Scientific Council of Friendship General Hospital of Nghe An. Patient information obtained from medical records was kept confidential and used solely for research purposes.

Acknowledgments

The authors acknowledge the Departments of Radiology and Urology, Friendship General Hospital of Nghe An, for their support in conducting the study.

REFERENCES

- [1] Chan, D. P. N., Abujudeh, H. H., Cushing, G. L., Jr., & Novelline, R. A. (2006). CT cystography with multiplanar reformation for suspected bladder rupture: Experience in 234 cases. *American Journal of Roentgenology*, 187(5), 1296–1302. <https://doi.org/10.2214/AJR.05.0971>
- [2] Coccolini, F., Moore, E. E., Kluger, Y., Ansaloni, L., Biffl, W., Leppaniemi, A., et al. (2019). Kidney and uro-trauma: WSES-AAST guidelines. *World Journal of Emergency Surgery*, 14, 54. <https://doi.org/10.1186/s13017-019-0274-1>
- [3] Deck, A. J., Shaves, S., Talner, L., Porter, J. R., & Corriere, J. N., Jr. (2000). Computerized tomography cystography for the diagnosis of traumatic bladder rupture. *The Journal of Urology*, 164(1), 43–46. [https://doi.org/10.1016/S0022-5347\(05\)67445-9](https://doi.org/10.1016/S0022-5347(05)67445-9)
- [4] Fouladi, D. F., Shayesteh, S., Fishman, E. K., & Johnson, P. T. (2020). Imaging of urinary bladder injury: The role of CT cystography. *Emergency Radiology*, 27(1), 87–95.
- [5] Gross, M., Mindelzun, R., & Jeffrey, R. B., Jr. (2010). The fat triangle sign: Improving diagnostic accuracy of extraperitoneal bladder rupture. *Abdominal Imaging*, 35(2), 253–255. <https://doi.org/10.1007/s00261-009-9502-2>
- [6] Haroon, S. A., Rahimi, H., Merritt, A., Baghdanian, A., Baghdanian, A., & LeBedis, C. A. (2019). Computed tomography (CT) in the evaluation of bladder and ureteral trauma: Indications, technique, and diagnosis. *Abdominal Radiology*, 44(12), 3962–3977. <https://doi.org/10.1007/s00261-019-02161-6>
- [7] Iverson, A. J., & Morey, A. F. (2001). Radiographic evaluation of suspected bladder rupture following blunt trauma: Critical review. *World Journal of Surgery*, 25(12), 1588–1591. <https://doi.org/10.1007/s00268-001-0154-9>
- [8] Karim, T., Topno, M., Sharma, V., Picardo, R., & Hastir, A. (2010). Bladder injuries frequently missed in polytrauma patients. *Open Access Journal of Urology*, 2, 63–65. <https://doi.org/10.2147/RRU.S9299>
- [9] Landman, W., Khurana, B., Briggs, A., Fairweather, M., Cooper, Z., Riviello, R., & Sodickson, A. D. (2015). BWH emergency radiology-surgical correlation: Intraperitoneal urinary bladder rupture. *Emergency Radiology*, 22(6), 713–716. <https://doi.org/10.1007/s10140-015-1323-8>
- [10] Mee, S. L., McAninch, J. W., & Federle, M. P. (1987). Computerized tomography in bladder rupture: Diagnostic limitations. *The Journal of Urology*, 137(2), 207–209. [https://doi.org/10.1016/S0022-5347\(17\)43954-1](https://doi.org/10.1016/S0022-5347(17)43954-1)
- [11] Morgan, D. E., Nallamala, L. K., Kenney, P. J., Mayo, M. S., & Rue, L. W., III. (2000). CT cystography: Radiographic and clinical predictors of bladder rupture. *American Journal of Roentgenology*, 174(1), 89–95. <https://doi.org/10.2214/ajr.174.1.1740089>
- [12] Pao, D. M., Ellis, J. H., Cohan, R. H., & Korobkin, M. (2000). Utility of routine trauma CT in the detection of bladder rupture. *Academic Radiology*, 7(5), 317–324. [https://doi.org/10.1016/S1076-6332\(00\)80005-7](https://doi.org/10.1016/S1076-6332(00)80005-7). PubMed
- [13] Pereira, B. M. T., de Campos, C. C. C., Calderan, T. R. A., Reis, L. O., Fraga, G. P., & de Andrade, A. F. (2013). Bladder injuries after external trauma: 20 years experience report in a population-based cross-sectional view. *World Journal of Urology*, 31(4), 913–917.
- [14] Quagliano, P. V., Delair, S. M., & Malhotra, A. K. (2006). Diagnosis of blunt bladder injury: A prospective comparative study of computed tomography cystography and conventional retrograde cystography. *Journal of Trauma*, 61(2), 410–421. <https://doi.org/10.1097/01.ta.0000229940.36556.bf>
- [15] Ramadan, A. A., Shaaban, M. S., & El-Sayed, A. M. (2017). Role of multi-detector computerized tomography in diagnosis of traumatic urinary bladder injuries. *The Egyptian Journal of Radiology and Nuclear Medicine*, 48(4), 1097–1104. <https://doi.org/10.1016/j.ejrm.2017.07.005>
- [16] Reddy, R. (2021). Role of ultrasonography in intraperitoneal bladder rupture with delayed presentation. *Cureus*, 13(12), e20159. <https://doi.org/10.7759/cureus.20159>
- [17] Sandler, C. M., Hall, J. T., Rodriguez, M. B., & Corriere, J. N., Jr. (1986). Bladder injury in blunt pelvic trauma. *Radiology*, 158(3), 633–638. <https://doi.org/10.1148/radiology.158.3.3945731>
- [18] Shin, S. S., Jeong, Y. Y., Chung, T. W., et al. (2007). The sentinel clot sign: A useful CT finding for the evaluation of intraperitoneal bladder rupture following blunt trauma. *Korean Journal of Radiology*, 8(6), 492–497.
- [19] Simon, L. V., Sajjad, H., & Lopez, R. A. (2021). Bladder rupture. In *StatPearls*. StatPearls Publishing.
- [20] Trinci, M., Cirimele, V., Cozzi, D., Galluzzo, M., & Miele, V. (2020). Diagnostic accuracy of pneumo-CT-cystography in the detection of bladder rupture in patients with blunt pelvic trauma. *La Radiologia Medica*, 125(10), 907–917. <https://doi.org/10.1007/s11547-020-01190-2>
- [21] Wu, T. S., Pearson, T. C., Meiners, S., & Daugherty, J. (2011). Bedside ultrasound diagnosis of a traumatic bladder rupture. *The Journal of Emergency Medicine*, 41(5), 520–523. <https://doi.org/10.1016/j.jemermed.2011.01.022>
- [22] Dang, Q. H., Nguyen, D. H., Le, T. D., & Nguyen, D. H. (2019). Diagnostic value of computed tomography cystography in the diagnosis of bladder trauma. *Vietnam Medical Journal*. [In Vietnamese].
- [23] Ngo, X. T., & Trinh, H. T. (2016). Evaluation of diagnostic and surgical treatment outcomes of extraperitoneal bladder rupture. *Ho Chi Minh City Medicine Journal*, 20(1), 66–71. [In Vietnamese].
- [24] Nguyen, M. A., & Nguyen, V. D. (2021). Clinical and paraclinical characteristics of patients with traumatic bladder rupture treated by laparoscopic surgery at Viet Duc Hospital. *Vietnam Medical Journal*, 504(1). [In Vietnamese]. <https://doi.org/10.51298/vmj.v504i1.850>
- [25] Tran, L. L. P., Nguyen, V. B., & Tran, V. S. (2003). Diagnosis of complex lower urinary tract injuries in severe pelvic fractures. *Ho Chi Minh City Medicine Journal*, 7(1), 115–119. [In Vietnamese].
- [26] Vu, V. P. (2009). *Study on the diagnostic value of computed tomography in traumatic bladder rupture* [Master's thesis]. Hanoi Medical University. [In Vietnamese].