



Contrast-enhanced computed tomography abdomen versus diagnostic laparoscopy-based management in patients with penetrating abdominal trauma: a randomised controlled trial

Supreet Kaur¹ · Dinesh Bagaria¹ · Abhinav Kumar¹ · Pratyusha Priyadarshini¹ · Narendra Choudhary¹ · Sushma Sagar¹ · Amit Gupta¹ · Biplap Mishra¹ · Mohit Joshi¹ · Atin Kumar² · Shivanand Gamanagatti² · Kapil Dev Soni¹ · Richa Aggarwal¹ · Sreenivas Vishnubhatla³ · Subodh Kumar¹

Received: 16 May 2022 / Accepted: 9 August 2022

© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany 2022

Abstract

Purpose Penetrating abdominal trauma was traditionally managed by mandatory exploration, which led to high rates of non-therapeutic surgery and prolonged hospital stay. Diagnostic laparoscopy (DL) is a less-invasive alternative; however, it requires general anaesthesia and carries a potential risk of iatrogenic injuries. Contrast-enhanced computed tomography (CECT)-guided selective non-operative management (SNOM) may avoid surgery altogether, but there is apprehension of missed injury. Randomised trials comparing these two modalities are lacking. This study is aimed at comparing outcomes of these two management approaches.

Methods Hemodynamically stable patients with penetrating trauma to anterior abdominal wall were randomised in 1:1 ratio to DL or CECT-based management. Primary outcome was length of hospital stay (LOS). Secondary outcomes were rate of non-therapeutic surgery, complications, and length of intensive care unit (ICU) stay.

Results There were 52 patients in DL group and 54 patients in CECT group. Mean LOS was comparable (3 vs 3.5 days; $p = 0.423$). Rate of non-therapeutic surgery was significantly lower in CECT group (65.4 vs 17.4%, $p = 0.0001$). Rate of complications and length of ICU stay were similar. Selective non-operative management based on CECT findings was successful in 93.8% of patients; 2 patients had delayed surgery.

Conclusion In patients with penetrating trauma to anterior abdominal wall, DL and CECT-based management led to comparable hospital stay. Significant reduction in non-therapeutic surgery could be achieved using a CECT-based approach.

Trial registration Clinical trials registry-India (CTRI/2019/04/018721, REF/2019/01/023400).

Keywords Penetrating injury · Abdominal trauma · Non-operative management · Anterior abdominal stab wounds · Diagnostic laparoscopy

Introduction

Management of penetrating abdominal trauma has evolved from mandatory exploratory laparotomy to ‘selective conservatism’ [1–4]. The basic principle of selective non-operative management (SNOM) is that examinable stable patients can be managed with serial clinical examination, thus, reducing the rate of non-therapeutic surgery.

However, SNOM with serial clinical examination alone may lead to delay in detection of serious injuries warranting surgery in up to 20% of patients, thereby increasing the risk of morbidity [5]. SNOM with SCE alone may also not be feasible in understaffed centres or centres with less experience of such protocol [6]. To increase the accuracy of

✉ Subodh Kumar
subodh6@gmail.com

¹ Division of Trauma Surgery and Critical Care, JPN Apex Trauma Center, All India Institute of Medical Sciences, New Delhi, Delhi 110029, India

² Department of Radiology, JPN Apex Trauma Center, All India Institute of Medical Sciences, New Delhi, India

³ Department of Biostatistics, All India Institute of Medical Sciences, New Delhi, India

SNOM, screening tests like contrast-enhanced computerised tomography (CECT) torso and diagnostic laparoscopy (DL) have been added in the management algorithms of penetrating abdominal trauma over the last two decades [7, 8].

Diagnostic laparoscopy allows thorough inspection of the peritoneal cavity, and is associated with lesser pain, wound infection, pulmonary complications, and shorter hospital stay than exploratory laparotomy [9, 10]. However, requirement of general anaesthesia, operating room availability and higher cost of treatment are limiting factors [11].

The widespread availability of CECT, speed and ease of performance, improved quality of images and lower cost compared to DL have led to more frequent use of this modality in management of penetrating abdominal trauma recently [7]. Use of CECT abdomen has increased the accuracy of detecting injuries requiring intervention [12]. In 2009, the Eastern Association for the Surgery of Trauma (EAST) suggested that CECT should be strongly considered to facilitate initial management decisions in PAT [8]. However, its sensitivity for detection of hollow viscus and diaphragmatic injuries is low, for which, DL is considered more reliable [7].

The Western Trauma Association guidelines, 2018 recognised the need for randomised controlled trials to establish the role of SNOM, DL and exploratory laparotomy in penetrating abdominal injury [7]. The aim of this randomised controlled trial (RCT) was to define the role of CECT and DL in the management of low velocity penetrating injury to the anterior abdominal wall.

Methods

The study is reported as per the CONSORT guidelines.

Study design

The study was designed as a two-armed, parallel RCT. The primary researcher (SK) enrolled participants and assigned them to either of two groups in 1:1 ratio.

CECT group—Patients undergoing CECT torso.

DL group—Patients undergoing DL.

Study settings and participants

The trial was conducted at a level I trauma centre, after clearance from the Institute Ethics Committee (Ref. No. IECPG-82/28.02.2019). The study was registered in the Clinical Trials Registry-India (CTRI/2019/04/018721, REF/2019/01/023400).

All acutely injured patients presenting to the emergency department between May 2019 and February 2021 were assessed during secondary survey for eligibility in the trial. Hemodynamically stable patients aged 16–65 years with

low velocity penetrating injury to the anterior abdominal wall, who presented within 24 h of injury, were included. Anterior abdominal wall was defined as the region bounded bilaterally by the mid-axillary lines, superiorly by the fifth intercostal spaces at the level of the nipples, and inferiorly by the inguinal ligaments.

Exclusion criteria included hemodynamically unstable patients with pulse rate more than 120/min, blood pressure less than 90/60 mm Hg, presence of peritonitis, evisceration of bowel and/ or omentum, impalement, concomitant head injury, penetrating injuries of posterior abdominal wall, coagulation disorders, pregnancy, and any other concomitant injury requiring surgery.

Informed written consent was taken prior to inclusion in the study. For patients aged less than 18 years, consent of legal guardian was taken. Demographic and clinical data were recorded in a pre-structured pro forma.

Interventions

DL group

All patients in this group underwent DL after completion of secondary survey. The technique of DL has been previously described [13]. The penetrating injury wound was not used for port placement. Hemo-peritoneum, if any, was noted, and was graded as mild (< 500 mL), moderate (500–1000 mL) and gross (> 1000 mL). Further management was decided based on intraoperative findings. Surgery was considered as ‘non-therapeutic’, if intraoperative findings did not require any surgical intervention, and as ‘therapeutic’, when intraoperative findings warranted a surgical procedure. Patients with mild to moderate hemo-peritoneum with no active bleeding were categorised as ‘non-therapeutic surgery’. Reasons for conversion from DL to laparotomy were noted. Stable patients were allowed oral diet after 6 h and were discharged in case of uneventful recovery after 24–48 h of admission. Patients were advised to report to the emergency department if any danger sign (abdominal pain, distension, fever, discharge from wound, or vomiting) was present. Otherwise, they were advised to follow up in outpatient department after 7 days.

CECT group

After initial evaluation, the patients underwent CECT torso (abdomen and chest). Use of oral and rectal contrast were decided on a case-to-case basis. In focussed assessment with sonography in trauma (FAST) negative patients, CECT was acquired as a single venous phase at 55–60 s after administration of 75–80 mL intravenous iohexol at the rate of 3–4 mL/s. In FAST positive patients, arterial phase was also acquired at 25–35 s.

Management algorithm as depicted in Fig. 1 was followed. Based on clinical status and CECT findings, patients underwent DL or exploratory laparotomy, which was considered as ‘early surgery’, or SNOM. The final decision regarding management was taken by the attending consultant. Patients selected for SNOM were monitored with 4-hourly clinical examination. All patients were kept nil by mouth initially. Non-operative intervention (NOI), such as angio-embolisation and image-guided procedures, were performed when indicated; procedure done and any complications thereof, were noted. Stable patients were allowed oral diet at the discretion of the attending consultant but not earlier than 6 h. Patients were discharged in case of uneventful recovery after 24–48 h of admission. Patients were advised to report to the emergency department if any danger sign (abdominal pain, distension, fever, discharge from wound, or vomiting) was present. Otherwise, they were advised to follow up in the outpatient department after 7 days. Deviation from the expected course, if any, was noted. Patients who developed signs of peritonitis or haemodynamic instability

during NOM were managed by DL or exploratory laparotomy, at the discretion of the attending consultant, which was considered as ‘delayed surgery’. Surgery was recorded as ‘non-therapeutic’ or ‘therapeutic’, as in the DL group.

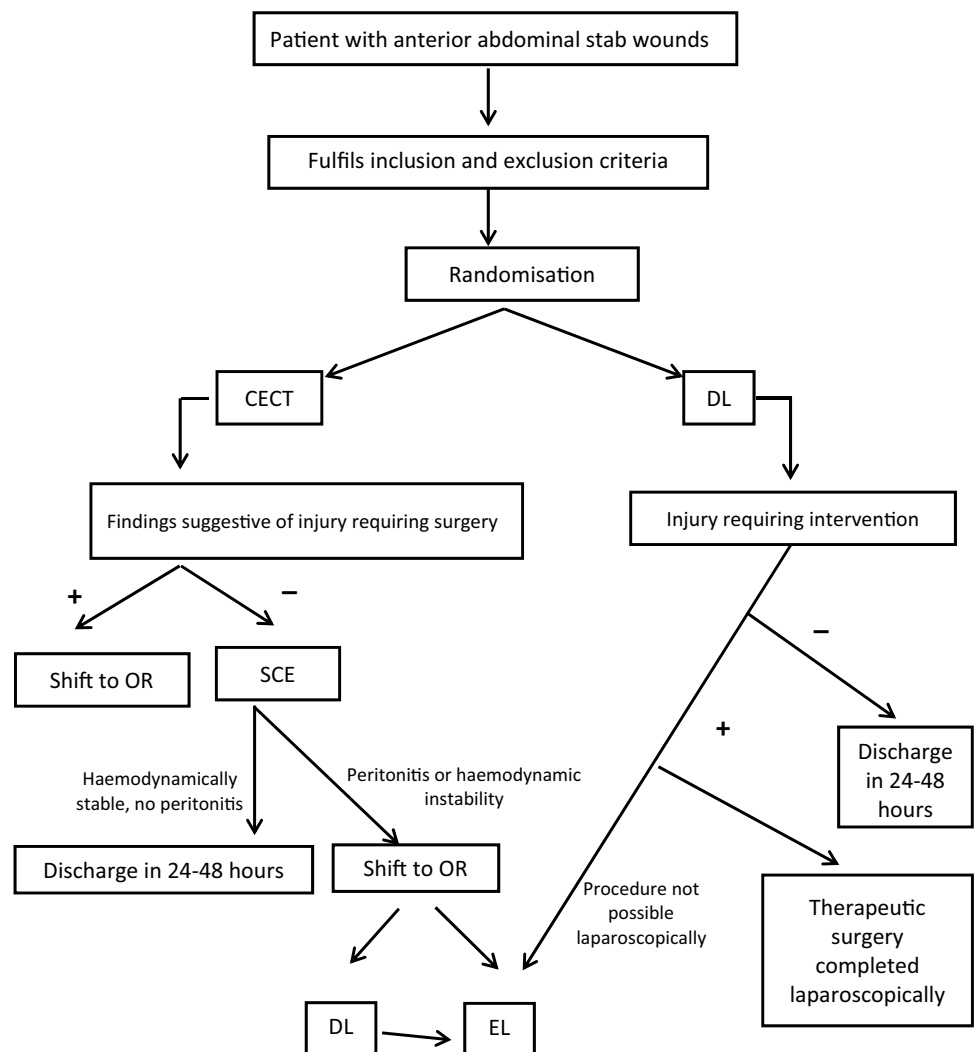
In both groups, patients were managed round-the-clock by trauma surgery residents with at least three years of surgical training. Decision of discharge was taken by the attending consultant. Criteria for discharge included haemodynamic stability, tolerance of oral diet, pain manageable with oral analgesics and absence of peritonitis on abdominal examination. All patients were followed up physically in the outpatient department or by telephonic interview at or after 30 days post discharge.

Local wound exploration was not done in any group.

Outcomes

Primary outcome was length of hospital stay (LOS), defined as number of days from admission to time of discharge. Secondary outcomes included rate of non-therapeutic surgery,

Fig. 1 Flow chart showing management protocol. *CECT* contrast-enhanced computed tomography, *OR* operation room, *SCE* serial clinical examination, *DL* diagnostic laparoscopy, *EL* exploratory laparotomy



length of Incentive Care Unit (ICU) stay, rate of complications, in-hospital mortality, time to oral feeding (liquid and solid), time to first defecation, and 30-day readmission rate.

Sample size

Sample size was calculated based on a study by Matsevych et al. [14], in which LOS in patients undergoing DL was 3.1 days, compared to 2 days in patients undergoing NOM. To detect a difference in LOS of 1.1 days (assuming a common standard deviation of 2 days) in two-sided t test with 5% α error and 80% power, 53 patients were required in each group.

Randomisation

Randomisation was done by a statistician who was not involved in the trial. Random sequence generation was done with a computer-generated list of random numbers obtained from a Microsoft Excel spreadsheet to ensure a 1:1 allocation ratio. Block randomisation was performed with block sizes of 6 and 4 with the same spreadsheet. Allocation concealment was achieved with sequentially numbered, sealed, opaque envelopes. No blinding was applied.

Statistical analysis

Intention to treat analysis was performed. Quantitative variables were summarised as mean \pm standard deviation (SD) and qualitative variables as proportion (%). Comparison of quantitative variables was carried out using Student's *t* test or Wilcoxon's rank sum test, as appropriate. Chi-square test and Fisher's exact test were used to compare qualitative variables between the two study groups. All analyses were performed using Stata[®] version 15.1; *p* value less than 0.05 was considered statistically significant.

Results

A total of 186 patients with anterior abdominal wall stab wounds presented to the emergency department during the study period. Of these, 76 patients did not fulfil the inclusion criteria and two patients refused to participate in the trial (Fig. 2). Two patients who had tested positive for coronavirus disease 2019 (COVID-19), could not be randomised as the hospital policy during the pandemic period did not allow laparoscopy in COVID-19 patients. Thus, 106 patients were randomised.

Fifty-four patients were randomised to CECT and 52 to DL. One patient allocated to DL group withdrew consent for surgery after randomisation and underwent CECT. This

patient was included in DL group for intention to treat analysis (Fig. 2).

Demographic variables and pattern and severity of injury were comparable in the two groups (Table 1). Mean number of penetrating injuries per patient was 1.4 ± 1.1 . Twenty-eight (26.4%) patients had more than one wound. Fifteen patients (14.2%) sustained thoraco-abdominal injuries, of which, 11 (10.4%) had left-sided and 4 (3.8%) had right-sided wounds.

Selective non-operative management (SNOM)

The various injuries detected on CECT are enumerated in Table 2. Out of 54 patients in the CECT group, peritoneal breach was identified in CT scan in 28 (51.8%) patients. Of these, 21 (38.9%) patients underwent early surgery and 7 were selected for NOM (three had solid organ injury—one had mild free fluid in pelvis without any other apparent injury, and two had only peritoneal breach). Twenty six (48.1%) patients, who had no peritoneal breach on CT scan, were selected for non-operative management (NOM). Thus, overall, 33 (61.1%) patients were selected for NOM. SNOM was successful in 31 (93.9%) patients and unsuccessful in 2 patients (6.1%) with peritoneal breach.

Surgical management

In the CECT group, 21 (38.9%) patients were planned for early surgery. Six patients were managed laparoscopically (of which, 5 were therapeutic) whilst 15 patients had laparotomy, of which, 12 were therapeutic. Two patients (3.7%) underwent delayed surgery; one after 7 h due to development of signs of peritonitis, and another after 14 h due to an expanding rectus muscle hematoma. The median time taken from admission to the operating room was 6 h (IQR 1–14).

In DL group, 51 patients underwent DL and one patient, who refused consent for DL after randomisation, had CECT and subsequently underwent EL, based on CECT findings. In DL, 21 patients appeared to have injuries that needed further operative management, which was completed laparoscopically in 2 patients. Nineteen patients were converted to laparotomy; however, after open exploration, only 16 patients were found to have injuries that needed intervention. Median time from admission to operating room was 4 h (IQR 0.5–18).

Intraoperatively, peritoneal breach was present in all 23 patients undergoing surgery in CECT group, and in 37 of 52 (71.2%) patients in DL group.

Length of hospital stay

Mean LOS was 3 ± 2.3 days in DL group and 3.5 ± 4.1 days in CECT group. The difference in length of hospital stay

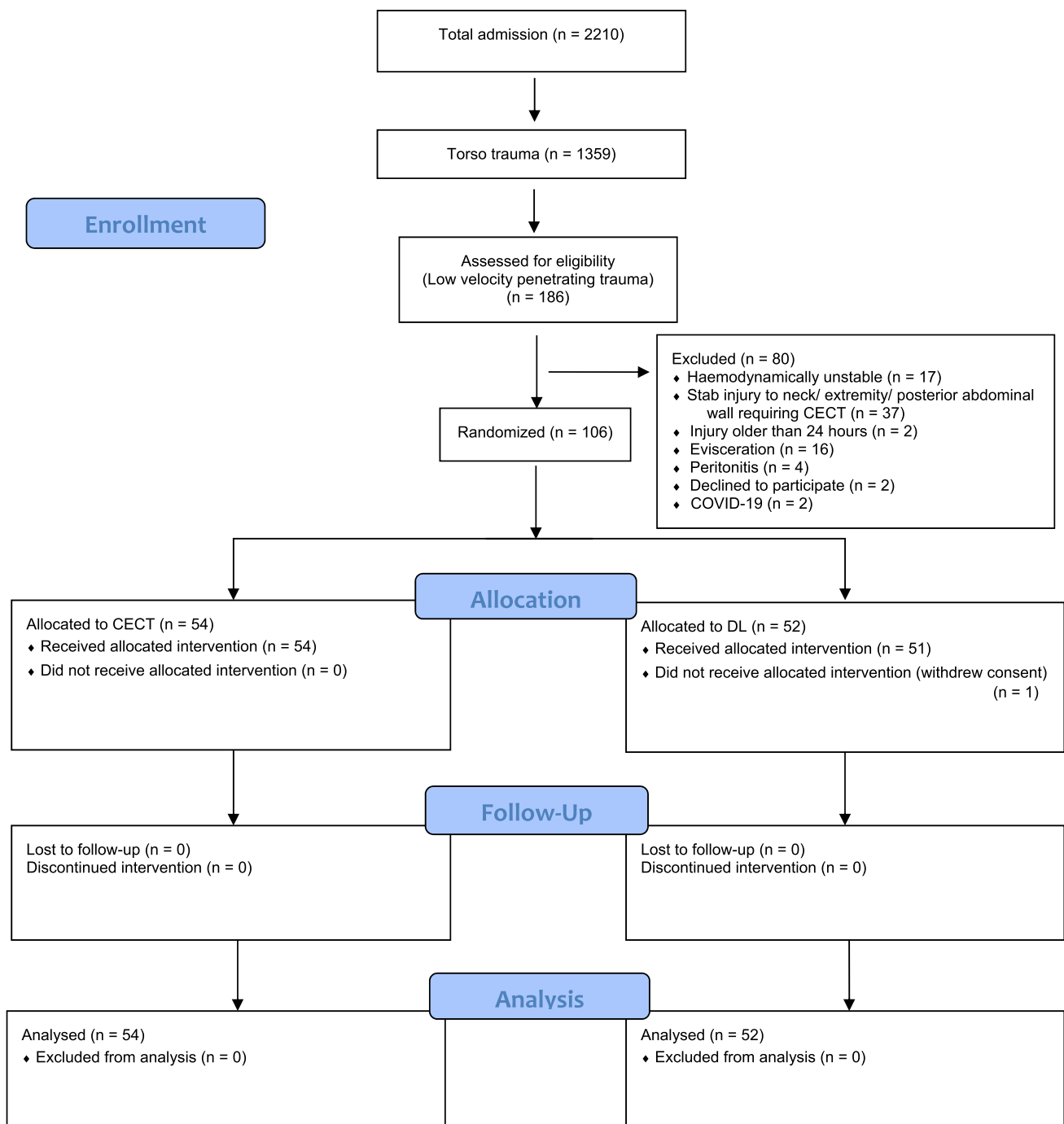


Fig. 2 CONSORT flow diagram

between the two groups was not significant ($p = 0.423$), with effect size—0.51 and 95% confidence interval of 43.4 to 18.3. Median LOS was 2.5 days (IQR 1–4) in DL group and 3 days (IQR 1–4) in CECT group. However, the difference did not achieve statistical significance ($p = 0.985$). Median LOS in the subset of CECT group patients who underwent SNOM was 24 h (IQR 24–48). Stratified

analysis showed that presence of chest drain did not have an influence on LOS ($p = 0.751$).

Secondary outcomes

As per intention to treat analysis, rate of non-therapeutic surgery was 7.4% (4/54) in the CECT group and 65.4% (34/52)

Table 1 Comparison of baseline demographics and injury characteristics

	DL group (<i>n</i> = 52)	CECT group (<i>n</i> = 54)
Male, <i>n</i> (%)	49 (94.2)	53 (98.1)
Female, <i>n</i> (%)	3 (5.8)	1 (1.9)
Age in years (Mean ± SD)	27.3 ± 9.1	28.9 ± 9.4
BMI in kg/m ² (Mean ± SD)	23.3 ± 3.3	23.1 ± 3.6
Injury duration in hours (Mean ± SD)	2.7 ± 2.9	2.2 ± 1.7
ISS (Mean ± SD)	4 ± 3.3	4.4 ± 4.5
NISS (Mean ± SD)	5.6 ± 5.1	6.6 ± 7.1
Pneumo ± hemothorax, <i>n</i> (%)	3 (5.8)	5 (9.2)
Pulse per minute (Mean ± SD)	91.9 ± 12.5	90.3 ± 12.1
SBP in mm Hg (Mean ± SD)	120 ± 11.2	124.8 ± 12
MAP in mm Hg (Mean ± SD)	93.7 ± 7.5	91 ± 8.1
FAST positive, <i>n</i> (%)	13 (25)	11 (20.4)
Number of wounds per patient (Mean ± SD)	1.3 ± 1.3	1.5 ± 0.8
Area of wound (Mean ± SD)	3.2 ± 2.8	3.4 ± 3.2
Associated injuries, <i>n</i> (%)	15 (28.8)	21 (38.9)
Head and neck	5	5
Upper chest	2	1
Extremity	8	15

DL diagnostic laparoscopy, CECT contrast-enhanced computed tomography, SD standard deviation, BMI body mass index, ISS injury severity score, NISS new injury severity score, MAP mean arterial pressure, FAST focussed assessment with sonography in trauma

Table 2 CECT findings

CECT finding	<i>n</i> (%)	
Peritoneal breach	28 (51.8)	
Intra-abdominal injury	23 (42.6)	
Pneumoperitoneum	Specks of air	7 (13)
	Gross	2 (3.7)
Hollow viscus injury	Bowel wall discontinuity	3 (5.6)
	Bowel wall thickening	2 (3.7)
	Non-enhancing bowel wall	1 (1.8)
Hemo-peritoneum	Mild	12 (24.1)
	Moderate	4 (7.4)
	Gross	1 (1.8)
Mesenteric injury	Stranding	7 (13)
	Contrast extravasation	1 (1.8)
Diaphragmatic injury	4 (7.4)	
Thoracic injury	11 (20.4)	

DL diagnostic laparoscopy, CECT contrast-enhanced computed tomography

in the DL group; the difference was statistically significant ($p = 0.0001$). If only the patients undergoing surgery in the CECT group are considered, rate of non-therapeutic surgery was 17.5% (4/23); the difference was still statistically significant ($p = 0.0001$).

Non-therapeutic laparoscopic surgery was done in 30 patients in the DL group and in one in the CECT group. Non-therapeutic laparotomy was done in 4 patients in DL

group and 3 in CECT group. Indication for laparotomy in the 4 patients in the DL group was peritoneal breach with hemo-peritoneum. In the CECT group, the indications were transverse meso-colon hematoma ($n = 1$), pneumoperitoneum ($n = 1$) and suspected omental injury ($n = 1$). One patient in CECT group underwent non-therapeutic DL in view of pneumoperitoneum.

Seven (6.6%) patients required ICU care, of which, 5 patients were in ICU for less than 24 h. Four of these patients were from DL group and one from CECT group. Median length of ICU stay was not significantly different between the two groups ($p = 0.234$).

Nine (17.3%) patients in DL group and 7 (13%) in CECT group developed complications during the course of hospital stay. The difference was not significant ($p = 0.532$) (Table 3). Major complications (higher than Clavien–Dindo grade II or major anaesthetic complications) occurred in 5 patients in CECT and 2 patients in DL group. All complications occurred in patients undergoing surgery.

There was one mortality in the entire cohort (0.9%). This patient was randomised to CECT group and underwent early surgery following diagnosis of duodenal and jejunal injury.

Two patients in the DL group and three in the CECT group needed readmission; the difference in readmission rate was not significant ($p = 0.509$). All readmissions occurred in patients who had undergone surgery (Table 4). None of the readmissions were due to missed injury.

Patients were started on liquid diet after 1.2 ± 0.9 days in DL and 1 ± 1.2 days in CECT group; the difference was

Table 3 Comparison of outcomes between two groups

Outcomes	DL group (n=52)	CECT group (n=54)	p value
Length of hospital stay in days (Mean ± SD)	3 ± 2.3	3.5 ± 4.1	0.423
Median length of hospital stay in days (IQR)	3 (1–4)	3.5 (1–3)	0.985
Time to operating room in hours (Mean ± SD)	5.4 ± 4.5	5.5 ± 3.2	0.383
Non-therapeutic surgery, n/N (%)	34/52 (65.4)	4/23 (17.4)	0.0001
Need for ICU stay, n (%)	5 (9.6)	2 (3.7)	0.364
Patients requiring ICU stay > 24 h, n (%)	1 (1.9)	1 (1.8)	0.491
Length of ICU stay in hours (Mean ± SD)	3 ± 10.6	7.1 ± 4.9	0.234
Mortality, n (%)	0	1 (1.8)	0.509
Readmission, n (%)	2 (3.8)	3 (5.7)	0.509
Reoperation, n (%)	1 (1.9)	1 (1.8)	0.547
Need for PRBC transfusion, n (%)	8 (15.4)	8 (14.8)	0.935
Days to nasogastric tube removal (Mean ± SD)	0.7 ± 0.8	0.4 ± 0.8	0.094
Number of days to start liquid diet (Mean ± SD)	1.2 ± 0.9	1 ± 1.2	0.464
Number of days to start solid diet (Mean ± SD)	1.8 ± 1.1	1.4 ± 1.2	0.017
Number of days to first stool (Mean ± SD)	2.1 ± 1.1	1.8 ± 1.2	0.033
Overall complications, n (%)	8 (15.3)	7 (13)	0.937
Clavien–Dindo grade I–II complications, n (%)	6 (11.5)	2 (3.7)	0.157
Clavien–Dindo grade III–V complications, n (%)	2 (3.8)	5 (9.3)	0.438
Surgical complications, n	SSSI	4	1
	DSSI	0	1
	Paralytic ileus	2	2
	Pseudocyst	0	1
	Respiratory complications, n		
	Pleural effusion	0	1
	Laryngospasm	1	0
	Bronchospasm	1	0
	ARDS	0	1

DL diagnostic laparoscopy, CECT contrast-enhanced computed tomography, SD standard deviation, ICU intensive care unit, IQR interquartile range, PRBC packed red blood cells, SSSI superficial surgical-site infection, DSSI deep surgical-site infection, ARDS acute respiratory distress syndrome

Table 4 Details of readmission

Variable	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
Group	CECT	DL	DL	CECT	CECT
Injury	Grade III pancreatic injury, stomach	Multiple jejunal perforations	Rectus muscle injury with bleeding	Perforation of splenic flexure of colon and retroperitoneal hematoma	Diaphragmatic injury
Management	Primary repair of stomach, pancreatic drainage	Resection and anastomosis of jejunum	Haemostasis and repair	Primary repair of colon	Repair of diaphragm rent
LOS (days)	16	5	1	5	3
Days post discharge	5	20	7	9	8
Complication	Pseudocyst	SAIO	DSSI	Intra-abdominal abscess	Pleural effusion
Clavien–Dindo grading	III B	II	I	III A	III A
Management	Endoscopic cystogastrostomy	Non-operative	Drainage of abscess	USG guided pigtail drainage	Refused treatment

DL diagnostic laparoscopy, CECT contrast-enhanced computed tomography, LOS length of hospital stay, SAIO subacute intestinal obstruction, DSSI deep surgical-site infection

not significant ($p=0.464$). However, time to initiation of solid diet was significantly longer in DL group (1.8 ± 1.1 vs 1.4 ± 1.2 days, $p=0.017$).

Discussion

Multiple studies over the last few decades have demonstrated unacceptably high rates of non-therapeutic laparotomy due to mandatory exploration, hence it is no longer considered the gold standard treatment [2, 4]. No single clear alternative treatment has taken its place. WTA/EAST guidelines provided a review of various treatment modalities, and acknowledge need for further studies to establish clarity, thus leaving the final decision to discretion of the treating surgeon [7, 8].

No difference in LOS was found in patients undergoing CECT or DL-guided management. In a retrospective study, Van Heut et al. found that use of CT scan helped to reduce the LOS of patients undergoing NOM from 3.2 to 1.8 days. They found the mean LOS of patients who underwent successful SNOM to be 1.5 days [15]. In our study, all patients randomised to CECT were observed for 24 h as per the study protocol, including patients who had only subcutaneous wound as demonstrated by CECT. On the contrary, patients who had non-therapeutic surgery in DL group were discharged after observation for 12–24 h. This might have led to a higher mean LOS in the CECT group of 0.5 days; however, the difference was not statistically significant. Sumislawski et al. suggested that patients with no peritoneal breach on DL can be discharged home from postoperative recovery room as early as 6 h [11]. However, patients undergoing DL in this study were not discharged at 6 h because of the usual practice of overnight observation in our institute. Similar delay in discharge after DL was also reported by Matsevych et al. in a study comparing DL with SNOM [14].

The most important finding of this study was a 58% reduction in the rate of non-therapeutic surgery in patients undergoing CECT-guided management. Although DL is less invasive than exploratory laparotomy, CECT can avoid surgery altogether, and thus, can potentially reduce any surgery- or anaesthesia-related morbidity. In principle, DL is a screening test. However, it is a surgical procedure requiring general anaesthesia, and patients consider it as a major procedure and are often reluctant to give consent. Thus, a policy of routine CECT rather than routine DL in stable patients of penetrating abdominal trauma is more likely to be successful in terms of patient compliance. In addition to greater patient comfort, this practice will take a load off the resource-constrained hospitals in low middle-income countries. The cost of DL is also higher than that of NOM [10].

Multiple studies have established the accuracy of CECT in identifying peritoneal breach and intraabdominal injury in penetrating abdominal trauma [12, 16]. Addition of

tractography was found to have high specificity and sensitivity, but negative predictive value remained low [17, 18]. Thorisdottir et al. reported that CT could identify hollow viscus injury in 76% patients. Sensitivity was reported as 58% for stab wounds. No difference in sensitivity with use of gastrointestinal contrast was found [19]. In our study CECT found peritoneal breach in 51% of patients.

Two patients had non-therapeutic surgery based on specks of pneumoperitoneum on CECT. These were later attributed to the stab wound tract. In patients with intact peritoneum, presence of any intraperitoneal air is considered pathological and would mandate a surgical exploration. However, in penetrating injury, there is a possibility that air may be introduced through the wound tract. Therefore, presence of minimal amount of intraperitoneal air may not be because of bowel injury. Kong et al. did not find intraabdominal injury in a third of patients who demonstrated pneumoperitoneum on erect chest X-ray [20]. However, attributing pneumoperitoneum to air entering through stab tract carries the risk of missing an injury, as was the case with one patient in our study. Further research is warranted to decide the best management for these patients—serial clinical examination or DL.

In this study, we did not perform local wound exploration in any patient, as this practice may not be useful in puncture wounds and has been found to be associated with high rates of non-therapeutic surgery. Moreover, it may be painful as local anaesthesia is often not adequate, and is particularly difficult in obese patients [21].

The postoperative course of patients in the DL and CECT groups was not markedly differently in terms of LOS and complications, but the latter had earlier return of bowel function and were started on solid diet significantly earlier compared to DL group. This could be because patients not requiring surgery in CECT group had no postoperative ileus. The rate of complications in our study was within the range reported in the literature [1, 22, 23].

In this study, complications in both groups occurred only in patients undergoing surgery. Two patients in DL group who had had a non-therapeutic surgery developed anaesthesia-related complications. Although these numbers are too small for any meaningful comparison, these complications could have been entirely avoided if CECT was used as a screening tool. Although none of the patients undergoing DL in this study had iatrogenic injury, it is a potential risk, which can be obviated by replacing DL by CECT as a screening tool. Laparoscopic surgery requires considerable skill and its results may not be uniformly reproducible [24]. There are also reports indicating missed injuries, as laparoscopic bowel walk is a demanding procedure. In a systematic review, O'Malley et al. reported 83 missed injuries in a cohort of 2569 patients undergoing DL for penetrating abdominal trauma [24].

There is no recommendation regarding the use of antibiotics in patients undergoing NOM following penetrating injury. In the CECT group, 29 patients who underwent SNOM received a single dose of prophylactic antibiotic, whilst 3 patients received more than one dose. None of these patients developed any wound-related complications. Thus, a single dose of prophylactic antibiotic may be considered adequate for patients undergoing SNOM.

To the best of our knowledge, this is the largest randomised controlled trial comparing DL and CECT in stable patients with penetrating abdominal trauma. However, it is not without limitations. Once screening with either CECT or DL was done, further management was as per the discretion of the treating surgeon. This might have led to some variability in patient management, but these variabilities are always present in clinical practice, and this flexibility in the study protocol ensures more generalisability of our study. Mandatory observation for 24 h was done in all patients who underwent CECT, which could have affected the primary outcome. Lack of long-term follow up may limit identification of sequelae, such as wound-site or port-site hernias. Blinding of patients was not possible in this study for obvious reasons. Incidence of missed injuries might have been a more relevant primary outcome but the sample size in that case would have been too high for a single centre study. A multicentre study with missed injury as primary outcome is required to assess the generalisability of CECT-based SNOM of patients with penetrating abdominal trauma.

Conclusion

Length of hospital stay was similar in patients with penetrating injury to the anterior abdominal wall who underwent CECT or DL-based management. Rate of non-therapeutic surgery was significantly lower in patients having CECT-based management. Use of CECT as a screening tool did not lead to any unacceptable increase in missed injuries. CECT-based management of patients with penetrating abdominal trauma may be adopted in centres with round-the-clock radiology and trauma surgery services.

Acknowledgements The authors gratefully acknowledge the residents of the Division of Trauma Surgery and Critical Care for their efforts and support for completion of this study.

Author contributions The study was conceptualised by SK and SK. All authors contributed to the study design. Material preparation, data collection and preparation of the first draft were done by SK. Analysis was done by SV. All authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

Funding No funds, grants or other support was received.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Ethical approval The study was approved by the Institute Ethics Committee (Ref. No. IECPG-82/28.02.2019) and was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Informed consent Informed written consent was taken from all individual participants or their legal guardians (in patients aged less than 18 years) for participation in the trial and for publishing their data and photographs.

References

1. Leppäniemi A. Nonoperative management of solid abdominal organ injuries: from past to present. *Scand J Surg SJS Off Organ Finn Surg Soc Scand Surg Soc.* 2019;108:95–100. <https://doi.org/10.1177/1457496919833220>.
2. Ball CG. Current management of penetrating torso trauma: nontherapeutic is not good enough anymore. *Can J Surg.* 2014;57:E36–43. <https://doi.org/10.1503/cjs.026012>.
3. Fouda EY, Magdy A, Emile SH. Selective non-operative management of anterior abdominal stab wounds with emphasis on the value of follow-up abdominal CT scanning. *Trauma.* 2018;20:194–202. <https://doi.org/10.1177/1460408617706389>.
4. Shaftan GW. Indications for operation in abdominal trauma. *Am J Surg.* 1960;99:657–64. [https://doi.org/10.1016/0002-9610\(60\)90010-6](https://doi.org/10.1016/0002-9610(60)90010-6).
5. Clarke DL, Allorto NL, Thomson SR. An audit of failed non-operative management of abdominal stab wounds. *Injury.* 2010;41:488–91. <https://doi.org/10.1016/j.injury.2009.10.022>.
6. Di Saverio S, Biscardi A, Tugnoli G, Coniglio C, Gordini G, Bendinelli C. The brave challenge of NOM for abdominal GSW trauma and the role of laparoscopy as an alternative to CT Scan. *Ann Surg.* 2017;265:e37–8. <https://doi.org/10.1097/SLA.0000000000001301>.
7. Martin MJ, Brown CVR, Shatz DV, Alam HB, Brasel KJ, Hauser CJ, et al. Evaluation and management of abdominal stab wounds: a Western Trauma Association critical decisions algorithm. *J Trauma Acute Care Surg.* 2018;85:1007–15. <https://doi.org/10.1097/TA.0000000000001930>.
8. Como JJ, Bokhari F, Chiu WC, Duane TM, Holevar MR, Tandoh MA, et al. Practice management guidelines for selective nonoperative management of penetrating abdominal trauma. *J Trauma.* 2010;68:721–33. <https://doi.org/10.1097/TA.0b013e3181cf7d07>.
9. Lin H-F, Wu J-M, Tu C-C, Chen H-A, Shih H-C. Value of diagnostic and therapeutic laparoscopy for abdominal stab wounds. *World J Surg.* 2010;34:1653–62. <https://doi.org/10.1007/s00268-010-0485-5>.
10. Leppäniemi A, Haapiainen R. Diagnostic laparoscopy in abdominal stab wounds: a prospective, randomized study. *J Trauma.* 2003;55:636–45. <https://doi.org/10.1097/01.TA.0000063000.05274.A4>.
11. Sumislawski JJ, Zarzaur BL, Paulus EM, Sharpe JP, Savage SA, Nawaf CB, et al. Diagnostic laparoscopy after anterior abdominal stab wounds: worth another look? *J Trauma Acute Care Surg.* 2013;75:1013–7. <https://doi.org/10.1097/TA.0b013e3182a1fde8> (discussion 1017–1018).
12. Salim A, Sangthong B, Martin M, Brown C, Plurad D, Inaba K, et al. Use of computed tomography in anterior abdominal

- stab wounds: results of a prospective study. *Arch Surg Chic Ill*. 1960;2006(141):742–5. <https://doi.org/10.1001/archsurg.141.8.745>.
13. Parajuli P, Kumar S, Gupta A, Bansal VK, Sagar S, Mishra B, et al. Role of laparoscopy in patients with abdominal trauma at level-I trauma center. *Surg Laparosc Endosc Percutan Tech*. 2018;28:20–5. <https://doi.org/10.1097/SLE.0000000000000379>.
 14. Matsevych OY, Koto MZ, Balabyeki M, Mashego LD, Aldous C. Diagnostic laparoscopy or selective non-operative management for stable patients with penetrating abdominal trauma: what to choose? *J Minimal Access Surg*. 2018. https://doi.org/10.4103/jmas.JMAS_72_18.
 15. van den Hout WJ, van der Wilden GM, Boot F, Idenburg FJ, Rhemrev SJ, Hoencamp R. Early CT scanning in the emergency department in patients with penetrating injuries: does it affect outcome? *Eur J Trauma Emerg Surg*. 2018;44:607–14. <https://doi.org/10.1007/s00068-017-0831-5>.
 16. Shanmuganathan K, Mirvis SE, Chiu WC, Killeen KL, Hogan GJF, Scalea TM. Penetrating torso trauma: triple-contrast helical CT in peritoneal violation and organ injury—a prospective study in 200 patients. *Radiology*. 2004;231:775–84. <https://doi.org/10.1148/radiol.2313030126>.
 17. Akkoca M, Balas S, Yilmaz KB, Tatar IG, Akinci M, Tokgoz S, et al. CT-guided tractography is a safe and complementary diagnostic tool in the management of penetrating abdominal trauma. *Asian J Surg*. 2019;42:148–54. <https://doi.org/10.1016/j.asjsur.2018.05.007>.
 18. Sarici İS, Kalayci MU. Is computed tomography tractography reliable in patients with anterior abdominal stab wounds? *Am J Emerg Med*. 2018;36:1405–9. <https://doi.org/10.1016/j.ajem.2017.12.065>.
 19. Thorisdottir S, Oladottir GL, Nummela MT, Koskinen SK. Diagnostic performance of CT and the use of GI contrast material for detection of hollow viscus injury after penetrating abdominal trauma. Experience from a level I Nordic trauma center. *Acta Radiol n.d.*:7.
 20. Kong V, Cheung C, Elsabagh A, Rajaretnam N, Varghese C, Bruce J, et al. Radiographic pneumoperitoneum following abdominal stab wound is not an absolute indication for mandatory laparotomy—a South African experience. *Injury*. 2021;52:253–5. <https://doi.org/10.1016/j.injury.2020.12.018>.
 21. Biffl WL, Leppaniemi A. Management guidelines for penetrating abdominal trauma. *World J Surg*. 2015;39:1373–80. <https://doi.org/10.1007/s00268-014-2793-7>.
 22. Cocco AM, Bhagvan S, Bouffler C, Hsu J. Diagnostic laparoscopy in penetrating abdominal trauma. *ANZ J Surg*. 2019;89:353–6. <https://doi.org/10.1111/ans.15140>.
 23. Bain K, Meytes V, Chang GC, Timoney MF. Laparoscopy in penetrating abdominal trauma is a safe and effective alternative to laparotomy. *Surg Endosc*. 2019;33:1618–25. <https://doi.org/10.1007/s00464-018-6436-1>.
 24. O'Malley E, Boyle E, O'Callaghan A, Coffey JC, Walsh SR. Role of laparoscopy in penetrating abdominal trauma: a systematic review. *World J Surg*. 2013;37:113–22. <https://doi.org/10.1007/s00268-012-1790-y>.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.