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Late closure of the open abdomen in emergency abdomino-pelvic surgery: Advanced indications to negative pressure wound therapy?

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Abstract

Background Damage control surgery(DCS) is a well-established approach in emergency laparotomy when physiologic instability necessitates an abbreviated operation. In severe intraabdominal infections(IAI), open abdomen(OA) with Negative Pressure Wound Therapy(NPWT) has shown significant efficacy to help reducing morbidity and mortality. Early definitive abdominal closure is recommended to minimize complications, though not always achievable.

Methods From 108 cases of DCS and OA with NPWT performed between February 2015 and February 2024, 72 consecutive patients treated for severe IAI were retrospectively reviewed. We comparatively analyzed clinical and perioperative data of patients treated with OA for ≤ 7 days(short OA) or for > 7 days(long OA), focusing on late OA closure(> 7 days). Primary outcome was overall 30-day survival, secondary outcome the primary fascial closure rate.

Results The main indication for OA was abdominal contamination. Fifty-six patients had short OA, 16 long OA. Overall mortality was 23.6%, with APACHE II score the only independent predictor (OR 1.9, 95% CI 1.25–2.92, $p = 0.003$). Fifty-two patients survived to achieve early closure and 12 late closure, respectively. Overall PFC rate was 92.2% (59 patients), 75% within late closure ($p = 0.001$). Compared to short OA, in long OA nine patients (56.3%, $p < 0.001$) experienced intraabdominal complications including enteroatmospheric fistula (EAF-3, 18.8%) and frozen abdomen (7, 43.8%); in 10 patients (87.5%, $p < 0.001$) NPWT regimen was modified to isolate and divert effluent or clean a contaminated field.

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Conclusions Late closure of the OA for IAI may significantly associate with EAF and frozen abdomen. In these challenging scenarios NPWT specific properties may be leveraged to address complex anatomical situations, extensive contamination, or the need for targeted wound-healing responses.

Keywords Negative pressure wound therapy, Open abdomen, Pelvic trauma, Intra-abdominal infection, Entero-atmospheric fistula

Introduction

In contemporary surgical practice, damage control laparotomy (damage control surgery-DCS) is a frequent and well-established approach for the management of critically ill patients presenting with severe trauma, emergent general surgical pathologies, or complex vascular interventions, particularly when physiologic instability necessitates an abbreviated operation; the open abdomen (OA) approach has become a fundamental aspect of this operative strategy [1].

Current indications for OA include abdominal trauma, necrotizing fasciitis of the abdominal wall, abdominal compartment syndrome (ACS), source control of severe intraabdominal infections or abdominal sepsis, as in generalized peritonitis and infected necrosis from severe acute pancreatitis[2]; a further indication for OA is planned relook via the open abdomen, delaying fascia closure[3].

Despite its portrayed benefits, OA represents a non-anatomic situation with the potential for severe adverse effects: in fact, prolonged OA may delay extubation, increase the risk for enteroatmospheric fistula (EAF) and frozen abdomen, and increase complications including the development of dense visceral adhesions up to frozen abdomen, the formation of EAFs (from 3.5 to 41% of cases) or the occurrence of surgical site infections (SSI) (in 10–18% of patients)[4, 5].

Mitigation strategies for these complications include aggressive nutritional support—preferably enteral nutrition when feasible—to promote tissue healing and reduce the risk of fistula formation, careful fluid management to prevent bowel edema, source control of sepsis combined with appropriate and timely antibiotic administration, although the most crucial strategy remains early fascial closure [6, 7]. Hence, it is recommended that abdominal fascia-to-fascia closure should be done as soon as the patient can physiologically tolerate it, possibly within 4–7 days (early closure of the OA) [6].

Physiology optimization is necessary to allow early abdominal closure. Nonetheless, in abdominal and pelvic emergency surgery, there are clinical scenarios where a combination of ongoing physiological instability and insufficient abdominal domain preclude definitive closure, or when adequate source control necessitates planned re-explorations. Moreover, abdominal complications arising during the course of OA management—such as the occurrence of enteroatmospheric fistula (EAF), abdominal wall fixity or persistent peritoneal contamination- may also prolong the necessity to access the abdominal cavity for longer intervals of time, and temporary abdominal closure (TAC) must be maintained [8].

In the OA technique, TAC with negative pressure wound therapy (NPWT) is considered one of the best management options [7]. The negative pressure regime is known to promote postoperative tissue healing, and in OA it helps protect viscera from the outer environment and at the same time provides means for guided closure of the abdominal wall [6]. NPWT supports sufficient drainage of peritoneal fluids along with other collateral benefits including active removal of bacterial contents and products, and of cytokines. It also prevents ACS, while preserving perfusion of the intestine and retroperitoneal organs [9, 10, 11]; commercial NPWT systems incorporating a protective visceral layer are generally preferred, as they facilitate effective fluid management, promote granulation tissue formation, and may reduce the risk of EAF compared to traditional methods such as vacuum packing alone [12, 13].

Abdominal sepsis and complications of abdominal surgery necessitating reoperation are the most frequent indications for OA In the UK [14]; under high-risk situations such as severe intraabdominal infections (IAI) or extensive visceral damage, OA with NPWT has shown ability to significantly help reduce morbidity and mortality [15]. Individuals with abdominal sepsis typically exhibit a lower rate of early fascial closure compared to trauma patients [16], though in general there is a paucity of data on the effect of closure timing on fascial closure rates in non-trauma settings, where the pathophysiology is different [17].

Moreover, evidence remains limited concerning the outcomes of OA managed with NPWT in challenging scenarios such as such as those involving prolonged OA duration.

The aim of this study is to analyze patients who were treated with damage control surgery (DCS), OA and NPWT for intra-abdominal infection, comparatively investigating the outcomes of early and late closure of the OA.

Materials and methods

Study design

A retrospective study was designed to assess the comparative clinico-pathological factors and outcomes of early vs late OA closure in a population on patients with IAI undergoing DCS and OA with NPWT.

From a prospective database of 196 patients treated with NPWT in the emergency setting at the Academic Unit of General Surgery Bonomo, Policlinico di Bari, Italy, between January 2015 and February 2024, a series of 108 consecutive DCS, OA with NPWT for abdominal pathology was retrieved and analyzed.

Patients treated for severe IAI were included [18]. Exclusion criteria were severe, uncontrollable intra-abdominal hemorrhage; intolerance to NPWT (absolute contraindication to OA with NPWT); OA performed in the context of vascular surgery; and cases without clinical or radiological evidence of intra-abdominal infection.

Seventy-two patients were identified that met the predefined inclusion and exclusion criteria and constituted the study cohort (Fig. 1). Patients were then stratified into two groups based on the duration of the open abdomen (OA): Group A included those with an OA duration of 7 days or fewer (short OA), while Group B comprised those with an OA duration greater than 7 days (long OA).

Early closure was defined as closure of the OA within 7 days from its creation, consistent with the 4–7-day interval recommended by international guidelines [6]. Late closure was defined as closure occurring more than 7 days after OA initiation.

The study protocol was approved by the Institutional Review Board (UniBa prot.n.7870/25), and all procedures were conducted in accordance with established ethical standards [19]. Informed consent was obtained from all participants. Results of this study are reported in accordance with the STrengthening the Reporting of OBservational studies in Epidemiology statement [20].

Data collection and outcomes

From deidentified patients' records we extracted demographic data including age, sex, comorbidities, ASA (American Society of Anesthesiologists) score [21]; C-reactive protein (CRP) levels (in mg/dL) and white blood cells (WBC) count (in n.cells/m m^3) at the beginning of OA treatment; Mannheim Peritonitis Index (MPI) [22] and Acute Physiology and Chronic Health Evaluation II (APACHE II) [23], as calculated within 24 h from either admission to intensive care unit (ICU) or end of the index operation.

Indication of surgery; DCS conducted as the first procedure or as a reintervention during the patient's admission; details of the type of peritoneal contamination (the presence of bowel perforation, peritoneal abscess, anastomotic leakage, or the leakage of bile, pancreatic fluid or urine) and factors complicating the presenting picture at the index procedure (eg haemorrhage), were also documented.

Postoperatively, the number of overall and abdominal complications specific to OA treatment (haemorrhage, EAF, other duct erosion resulting in leakage of abdominal bodily fluids and contamination of the peritoneal cavity, frozen abdomen), the length of ICU and in-hospital stay (in days), rates and details OA and fascia closure, NPWT treatment details including number of abdominal dressing changes, pressure settings and Bjork's classification at the beginning [24] and at the closure of the OA, in-hospital and 30-day mortality events were also retrieved.

Primary outcome was the rate of overall 30-day survival. Primary fascial closure, rates of long OA, of late OA closure and of overall and abdominal complications during OA treatment, overall length of stay in ICU in days, types of modification of NPWT parameters and of Bjork status of cases at the end of long OA were secondary outcomes.

Open abdomen procedure and perioperative management

The decision to proceed with an OA was made at the surgeon's discretion, based on the presence of coagulopathy, hypothermia and acidosis in patients presenting with severe peritonitis, with or without concurrent abdominal hemorrhage, intestinal ischemia, hemodynamic instability, or ACS. For OA treatments, commercial kits for Vacuum-Assisted Closure (VAC) therapy were used for NPWT (Ab Thera, KCI International, San Antonio, TX, USA or RENASYS AB Kit, Smith & Nephew, Memphis, TN, USA; Suprasorb-CNP®, Suprasorb CNP system, Lohmann & Rauscher, Austria-Germany) as recommended by the local Hospital Board [25].

Each of the kits used comprised three primary dressing components: a foam dressing, a drainage film or visceral protective layer, and an adhesive drape.

In all kits, the foam dressing consisted of large pieces of hydrophobic, reticulated, open-cell polyurethane foam (perforated foam in the case of the KCI system). This foam was cut to conform to the size and shape of the abdominal wound. Its purpose is to uniformly distribute negative pressure across the wound bed, working in conjunction with the visceral protective layer to facilitate fluid removal.

The visceral protective layer served as a physical barrier between the exposed abdominal viscera (bowel and other organs) and the foam dressing. This film, which is placed around the viscera to shield them while remaining permeable to negative pressure, varied between systems: a fenestrated, non-adherent, polyurethane-film-covered dressing in the AbThera kit; an elliptical-shaped, non-adherent, perforated, laminated polyurethane sheet in the Renasys system; and a double-layer drainage film made of transparent membranes with numerous, uniformly arranged perforations in the L&R Suprasorb-CNP system.

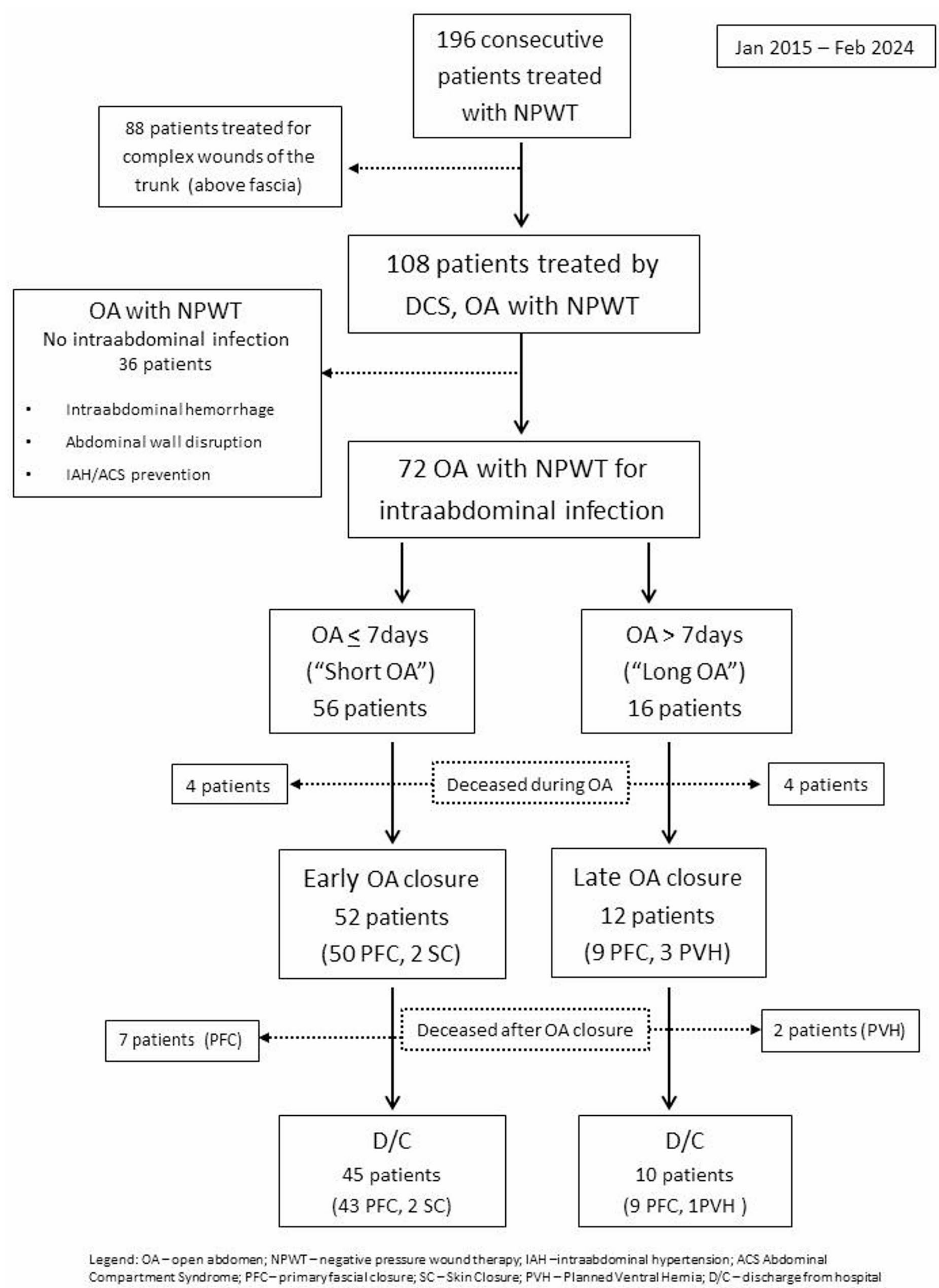

Fig. 1 Flow diagram with inclusion and exclusion criteria

All systems included adhesive drapes, also known as transparent film dressings or occlusion films. This is a crucial component that creates an airtight, occlusive seal over the entire wound and surrounding skin. The drape maintains the negative pressure within the abdominal cavity and isolates the abdominal contents from external contaminants.

Prior to kit positioning, meticulous hemostasis was achieved, the abdominal cavity was rinsed with saline solution and necrotic tissues were debrided, except for pancreatic necrosis [26]. The OA system was positioned as described in previous studies, with a perforated, non-adhesive sheet applied beneath the anterior abdominal wall, covering the entire abdominal viscera, set at continuous negative pressure mode between 75 and 125 mmHg as the standard initial setting [3, 6, 15, 27].

If there was suspicion of active bleeding due to coagulopathy or not amenable to surgical repair, NPWT was started at low pressures, – 25 to – 50 mmHg, monitoring closely the output [28].

If intestinal fistulae occurred while using NPWT, the negative pressure regimen was also modified: the intensity and continuity of negative pressure applied to the wound were reduced (– 25/– 50 mmHg, intermittent setting) [12]. In addition, fistulas were either isolated by applying visceral protection layer, foam and adhesive drape bearing a 2-cm hole over the fistula, where an ostomy bag was applied; or were excluded by applying a WhiteFoam dressing [29]. In the case the area where fistula occurred was buried in the abdomen, suction cap was positioned on one side of the laparotomy wound to slowly turn EAF into an enterocutaneous fistula.

After establishing the OA with NPWT at the index operation, change of the VAC dressing was planned every 48–72 h in the operating room or in a dedicated space in the ICU.

Planned relook took place on the occasion of each vacuum dressing change. OA was prolonged to facilitate further surgical re-exploration under the following conditions: persistent contamination or inadequate clearance of the peritoneal cavity, persistent visceral edema, or a sustained risk of developing ACS or a frozen abdomen.

Staged abdomen closure began since the first relook: on the occasion of each dressing change, attempts at incremental fascial and skin closure were made, with periods of NPWT interspersed with surgical attempts at closure, aiming for complete closure by the end of the OA treatment [8]. If tension-free closure was ultimately not achievable due to excessive fascial retraction, reconstruction with biosynthetic mesh was performed, usually with a "Bio-A" mesh (Gore Inc., Newark, DE, USA), positioned intraperitoneally [3].

Together with early goal-directed therapy, all patients received nutritional support with oral nutrition supplements with high-calories and high-protein products or through personalized high-calories/high-proteins parenteral nutrition (within acceptable renal and liver function), where intestinal function was not available [31].

Data synthesis and statistics

Categorical variables were presented as number of cases/total (%) whereas continuous variables were presented as mean ± standard deviation.

A comparative analysis between data relative to short-duration and long-duration OA and early and late closure of the OA was performed both in the overall study population and in the subgroup of patients who achieved definitive OA closure.

Univariable associations between dichotomous and categorical outcome variables were examined using Chi-square test/Fischer's exact test as appropriate. The ANOVA Kruskal–Wallis' test was used to compare differences in continuous variables. To identify independent risk factors for prolonged open abdomen, mortality, and failure to achieve definitive fascial closure, stepwise logistic regression analysis was performed. To this purpose, all factors that were significant at $P < 0.2$ were entered in the multivariable analysis model. Adjusted odds ratio, 95 per cent confidence intervals (CI), and adjusted p value were derived. Statistical analysis was conducted using the Statistical Package for Social Sciences software (SPSS®, ver.26.0.0, IBM, Armonk, New York, USA), with significance set at 0.05.

Results

Seventy two patients (37 M, 51.4%) with a mean age of 59.8 (range 16–86) years treated with DCS, OA with NPWT for peritonitis for IAI were examined (Fig. 1). More than one third of all patients presented multiple comorbidities (25 patients with three or more comorbidities 34.7%), more than one fourth were ASA 4 (20 patients, 27.7%), while overall APACHE II score (14.44 ± 7.6) and MPI (18.5 ± 8) indicated an overall moderate risk of mortality. In the majority of cases the source of infection was in the lower gastrointestinal tract, and in two thirds of cases OA was created during a reintervention for complications of abdominal surgery (Table 1).

After establishing the OA with NPWT at the index operation, the VAC dressing was systematically changed every 48–72 h in the operating room or in a dedicated space in the ICU in all patients.

Demographic characteristics did not show significant differences between patients receiving short OA or long OA (Table 1). Overall, 30-day mortality was 23.6%, predicted only by APACHE II score (Tables 2, 3). Eight patients died during OA, while nine after OA closure. There were no differences in the death rate between

Table 1 Demographic data of 72 patients undergoing DCS and OA with NPWT for severe intraabdominal infection

	All patients	N (%), Mean (± SD)		*p*
		Short OA (≤7 days)	Long OA (> 7 days)	
Patients	72	56	16	
Age (years)	59.8 ± 15.8	59.2 ± 14.7	61.9 ± 19.4	0.548
Gender M (%)	37 (51.4)	32 (57.1)	5 (31.3)	0.061
Comorbidities				
BMI	27.6 ± 3.3	27.7 ± 2.8	27.4 ± 4.8	0.850
Obesity	15 (20.8)	10 (17.9)	5 (31.3)	0.204
Hypertension	24 (33.3)	19 (33.9)	5 (31.3)	0.547
Malignancy	35 (48.6)	28 (50)	7 (43.8)	0.438
Cardiopathy	10 (13.9)	7 (12.5)	3 (18.8)	0.390
Diabetes	19 (26.4)	13 (23.2)	6 (37.5)	0.203
COPD	14 (19.4)	11 (19.6)	3 (18.8)	0.624
Chronic liver diasease	5 (6.9)	2 (3.6)	3 (18.8)	0.069
Renal disease	5 (6.9)	3 (5.4)	2 (12.5)	0.307
None	8 (11.1)	7 (12.5)	1 (6.3)	0.429
≥3 concurrent comorbidities	25 (34.7%)	18 (32.1)	7 (43.8)	0.283
Source of infection				
GI	56 (77.8)	43 (76.8)	13 (81.3)	0.500
IA non-GI source	20 (27.8)	15 (26.8)	4 (25)	0.582
Concurrent GI—IA	6 (8.3)	4 (7.1)	2 (12.5)	0.401
Indication to DCS + OA				
Anastomotic leakage	27 (37.5)	23 (41.1)	4 (25)	0.446
Infected pancreatic necrosis	6 (8.3)	4 (7.1)	2 (12.5)	
Bowel perforation	22 (30.6)	15 (26.8)	7 (43.8)	
Peritoneal abscess	17 (23.6)	14 (25)	3 (18.8)	
DCS + OA is a reintervention	48 (66.7)	38 (67.9)	10 (62.5)	0.453
Previous abdominal procedures (n.)				
0	22 (30.6)	18 (32.1)	4 (25)	0.279
1	37 (51.4)	30 (53.6)	7 (43.8)	
2	12 (16.7)	7 (12.5)	5 (31.3)	
3	1 (1.4)	1 (1.8)	0	
CRP	141 ± 71.4	139 ± 70.7	147.7 ± 77	0.714
WBC count (× 10^3/mm^3)	17.9 ± 6.7	17.5 ± 6.5	19.2 ± 7.1	0.404
Mean duration OA (days)	7.2 ± 8.2	4.1 ± 2.8	19.4 ± 10.1	
Mean number of looks	3.2 ± 3.4	1.79 ± 0.7	8.3 ± 4.3	

SD, standard deviation; OA, open abdomen; NPWT, negative pressure wound therapy; BMI, body mass index; ASA, American Society of Anaesthesiology; COPD, Chronic obstructive pulmonary disease; GI, gastrointestinal; IA, intraabdominal; CRP, C-reactive protein; WBC, white blood cell; APACHE II, Acute Physiology and Chronic Health Evaluation II score; MPI, Mannheim Peritonitis

Table 3 Multivariable analysis of risk factors for death during OA with NPWT

Factor	Exp (B)	95% CI	*p*
APACHE II Score	1.908	1.248–2.917	**0.003**

Values indicating statistical significance (whenever for a given test $p < 0.05$) were generally rendered in bold fonts to highlight results

Table 2 Univariable analysis of in-hospital mortality—All patients

	All patients—n.72	N (%), Mean (range, SD)		*p*
		Alive	Deceased	
	72	55	17	
Age	59.8 ± 15.8	57.5 ± 12.2	67 ± 12.1	**0.020**
APACHE II score	14.4 ± 7.6	11.2 ± 4.7	24.8 ± 5.8	**< 0.001**
MPI	18.5 ± 8	16.2 ± 6.5	26.1 ± 8	**< 0.001**
Presence of haemorrhage at index OA	7 (9.7)	3 (5.5)	4 (23.5)	0.049
Perforated, fixed small bowel**	5 (6.9)	4 (7.3)	1 (5.9)	0.663
Bile, pancreatic fluid and urine leak	4 (5.6)	4 (7.3)	0	0.332
Anastomotic leakage	27 (37.5)	19 (34.5)	8 (47.1)	0.257
OA procedure is a reintervention	48 (66.7)	37 (67.3)	11 (64.7)	0.532
Haemorrhage during OA	17 (23.6)	15 (27.3)	2 (11.8)	0.162
EAF	3 (4.2)	2 (3.6)	1 (5.9)	0.560
New-onset bile, pancreatic or urine leak	1 (1.4)	1 (1.8)	0	0.764
Frozen abdomen	11 (15.3)	9 (16.4)	2 (11.8)	0.490
Overall complications	41 (56.9)	26 (47.3)	13 (76.5)	**0.032**
Abdominal complications (overall)	15 (20.8)	11 (20)	4 (23.5)	0.754
NPWT regime modification	33 (45.8)	26 (47.3)	7 (41.2)	0.437
Long OA	14 (19.4)	10 (18.2)	4 (23.5)	0.431

**Perforated small bowel loop entrapped within adhesive peritonitis

Values indicating statistical significance (whenever for a given test $p < 0.05$) were generally rendered in bold fonts to highlight results

groups. Overall length of hospital stay in 55 surviving patients was 19.3 ± 15 days.

Patients with significantly higher APACHE II score experienced long OA (Table 4), which was more frequently associated to ASA 4 status. Of note, in long OA a significantly higher proportion of patients than in short OA experienced intraabdominal complications including enteroatmospheric fistula and frozen abdomen and, concurrently, the vast majority of patients being treated with long OA required modification of the NPWT regimen.

Contamination of the peritoneal cavity with bile, pancreatic fluid or urine, and presence of a perforated small bowel loop entrapped within adhesive peritonitis (making it impossible to stop leakage or create a stoma) were independent factors for long OA at multivariable analysis (Table 5).

Within long OA, late closure occurred in 12 (75%) of cases while in short OA in 52 (92.9%), though there were no significant differences between groups. The overall

Table 4 Univariable analysis of perioperative variables and duration of OA with NPWT—All patients

All patients (n. 72)	**N (%), Mean (± SD)**		***p***
	Short OA (≤7 days) 56 (100)	**Long OA (> 7 days) 16 (100)**	
Patient characteristics at index procedure			
APACHE II score	13.4 ± 7.3	18.2 ± 7.5	**0.024**
Mannheim Peritonitis Index	17.6 ± 8.1	21.7 ± 7	0.067
ASA 4	12 (21.4)	8 (50)	**0.030**
GI anastomosis leakage*	24 (42.9)	3 (18.8)	0.069
Haemorrhage	4 (7.1%)	3 (18.8)	0.179
Peritoneal leakage of bile, pancreatic fluid or urine	1 (1.8)	3 (18.8)	**0.032**
Perforated, fixed small bowel loop**	1 (1.8)	3 (18.8)	**0.032**
Perioperative outcomes during OA			
Intra-abdominal complications (any)	6 (10.7)	9 (56.3)	**< 0.001**
New-onset haemorrhage	2 (3.6)	3 (18.8)	0.069
EAF	0	3 (18.8)	**0.009**
New-onset bile, pancreatic fluid or urine leakage	0	1 (6.3)	0.222
Frozen abdomen	4 (7.1)	7 (43.8)	**0.002**
NPWT regime modification	19 (33.9)	10 (87.5)	**< 0.001**
Perioperative outcomes during admission			
Complications (overall)	28 (50)	11 (68.8)	0.415
Overall ICU stay (days)	12.2 ± 14.2	24 ± 15.2	0.089
OA closure	52 (92.9)	12 (75)	0.067
Death before OA closure	4 (7.1)	4 (25)	0.067
Death before 7 days	10 (17.9)	0	0.066
In-hospital OS n. (%)	45 (80.4)	10 (62.5)	0.127

SD, standard deviation; OA, open abdomen; NPWT, negative pressure wound therapy; GI, gastrointestinal; ICU, intensive care unit; EAF, Enteroatmospheric fistula; OS, overall survival

*gastrointestinal anastomosis

**Perforated small bowel loop entrapped within adhesive peritonitis

Values indicating statistical significance (whenever for a given test $p < 0.05$) were generally rendered in bold fonts to highlight results

Table 5 Multivariable analysis of risk factors for long OA

Factor	**Exp (B)**	**95% CI**	***p***
Perforated, fixed small bowel loop**	24.6	1.9–315.4	**0.014**
Peritoneal leakage of bile, pancreatic fluid or urine	24.9	1.9–311.3	**0.013**

**Perforated small bowel loop entrapped within adhesive peritonitis

Values indicating statistical significance (whenever for a given test $p < 0.05$) were generally rendered in bold fonts to highlight results

rate of primary fascial closure in patients who survived to achieve OA closure was 92.2% (59 patients). Fascial closure occurred significantly more in the early closure group (Tables 6, 7), while only patients who had a late closure experienced planned ventral hernia. Patient and perioperative factors, in general those indicating fixity of either the abdominal wall or of peritoneal viscera, were associated to lower rates of primary fascial closure. Multivariate analysis showed that only the presence of a frozen abdomen was a negative predictor of primary fascial closure, as the odds of achieving fascial closure among patients with a frozen abdomen were significantly lower compared to those without a frozen abdomen, equivalent to a 95% reduction in the odds.

Table 6 Univariable analysis of perioperative variables and late OA closure or Primary Fascial Closure

Patients surviving until OA closure (n. 64)	**N (%), Mean (± SD)**		***p***
	Early closure (≤ 7 days) 52 (100)	**Late closure (> 7 days) 12 (100)**	
Patient characteristics at index procedure			
Peritoneal leakage of bile, pancreatic fluid or urine	1 (1.9)	3 (25)	**0.019**
Perioperative outcomes during OA			
Enteroatmospheric fistula	0	2 (16.7)	**0.033**
Frozen abdomen	4 (7.7)	5 (41.7)	**0.009**
NPWT regime modification	18 (34.6)	10 (83.3)	**0.003**
Perioperative outcomes during admission			
OA closure			
Primary fascia closure	50 (96.2)	9 (75)	**0.001**
Skin closure only	2 (3.8)	0	
Planned ventral hernia	0	3	
In-hospital death (after OA closure)	7 (13.5)	2 (16.7)	0.539
Primary fascial closure	**No 5 (100)**	**Yes 59 (100)**	***p***
At index OA			
M/F	5/0	33/26	**0.022**
Presence of a stoma at index OA	2 (40)	3 (5.1)	**0.045**
Perforated, fixed small bowel **	3 (60)	0	**< 0.001**
During OA			
Frozen abdomen	2 (40)	0	**0.005**
Frozen abdomen	4 (80)	5 (8.5)	**0.001**

OA, open abdomen; NPWT, negative pressure wound therapy; GI, gastrointestinal; ICU, intensive care unit; EAF, Enteroatmospheric fistula

*gastrointestinal or ureteric anastomosis

**Perforated small bowel loop entrapped within adhesive peritonitis

Values indicating statistical significance (whenever for a given test $p < 0.05$) were generally rendered in bold fonts to highlight results

Table 7 Multivariable analysis of risk factors for fascia closure

Factor	**Exp (B)**	**95% CI**	***p***
Frozen abdomen	0.5	0.04–0.65	**0.022**

Values indicating statistical significance (whenever for a given test $p < 0.05$) were generally rendered in bold fonts to highlight results

Features and outcomes of patients achieving late OA closure were further analyzed. Table 8 shows primary indications, complications during OA or relative contraindications to OA, management and outcomes of the 10 patients who achieved hospital discharge after late OA closure. Eight were treated with OA with NPWT for over 21 days. Among these, we observed EAFs in two patients with a frozen abdomen, one of these two patients developed EAF twice in the course of OA, once at the level of the duodenum (Fig. 2) and, after one further month of admission, from likely the distal jejunum, as the opening could not be seen because it was buried deep in a frozen abdomen (Fig. 3); the duodenal EAF was treated with sutures three times and by taking the negative pressure settings to − 25 mmHg with intermittent aspiration before witnessing fistula healing. All other EAFs were successfully treated conservatively, with modifications to the NPWT settings. In all EAF cases high protein/high calories parenteral nutrition was personalized on patients' needs via a weekly nutritional review. Modifications to NPWT settings were made in all patients, with attenuated intensity of the negative pressure being the most commonly performed change to the standard settings, in 9/10 patients.

More than half of these 10 patients showed evidence of visceral adhesions or fixity at the first relook to change the vacuum dressing (Bjork 2 class); before OA closure, one third of patients had transitioned to Bjork class 3 or 4 (Table 9).

Discussion

The use of NPWT for OA has emerged as one of the preferred options for temporary abdominal closure(TAC), as NPWT is known to bring a number of benefits with respect to other available techniques, first of which the potential to achieve a high rate of fascia closure[3, 30, 6]. Under high-risk situations such as severe intraabdominal infections (IAI) or extensive visceral damage, OA with NPWT has shown ability to significantly help reduce morbidity and mortality [15].

This study examined patient and perioperative factors to compare the effect of short versus long OA with NPWT on survival (primary outcome) and primary fascial closure rate of patients treated by DCS for severe IAI.

Overall mortality was 23.6%, which is comparable to other series [3, 31]. Analysis showed that APACHE II score was the only factor predictive of mortality, which is consistent with previously published experience, including by this group. In a recent study on 113 septic patients treated with OA by Tartaglia et al. APACHE II score, ASA score IV and Clinical Frailty Score were factors independently associated with mortality, confirming the validity of these scores in critical patients' management [32].

Duration of OA did not impact on survival, while late closure of the OA was found to be significantly associated to lower rates of primary fascia closure (75%) with respect to when the OA was closed within a week from its creation (96%). A study of 344 damage control laparotomies demonstrated that early abdominal fascial closure can be achieved in the majority (63%) of damage control cases during the initial re-laparotomy [33].

The same study showed that fascial closure before 8 days was associated with fewer complications: 12% in those closed before 8 days and 52% closed after 8 days [34]. Similarly our results show that early closure of the OA was associated with significantly fewer overall and intraabdominal complications.

Independent factors predicting a long OA were the presence of peritoneal contamination from bile, pancreatic fluid or urine leak, and the presence of a deep seated infection, as in a perforated, adherent bowel loop. Deep surgical site infections have been identified as independent predictors of failure to close the OA in laparotomies for trauma [35]. Moreover, individuals with abdominal sepsis typically exhibit a lower rate of early fascial closure compared to trauma patients [16]. In fact, delayed fascial closure can be commonly achieved once all the intra-abdominal injuries have been addressed. In the setting of intra-abdominal sepsis or pancreatitis, delayed fascial closure is not as successful, mainly upon failure to control a persistent source of chemical or infectious contamination of the abdomen: the first surgical approach to control of the source of an IAI may not be sufficient, and further procedures may be necessary to control contamination or infection [36, [37].

Longer OA was significantly associated with an increased rate of abdominal complications, in particular EAF and frozen abdomen, with frozen abdomen being six times more frequent, and EAF occurring exclusively in the long OA group.

Closing the abdomen as early as possible is important as OA is a non-anatomical condition that, once created for an emergency need, can be tolerated by viscera and abdominal wall for a limited period of time; the longer the time period to fascial closure, the higher the complication rates especially EAF and frozen abdomen occur [6, 24, 38]. These are feared complications, known to increase with duration of open abdomen, and are associated with difficult management and high mortality rates [8, 39]. Frozen abdomen was an independent, negative predictor of primary fascial closure in this study.

The enteroatmospheric intestinal fistula can develop as a result of an anastomotic leak with exposed suture lines, traumatized bowel, and nontraumatized bowel, which has been exposed for a period of time. The exposed bowel is at risk of fistulisation, especially in a chronic OA and in the presence of synthetic meshes and infection; the foremost risk factors are the inability to perform primary abdominal facial closure in a timely manner, and deep space infections as intra-abdominal abscess [28].

Historically, NPWT has been criticized for its theoretical risk of increasing enterocutaneous fistulas, although the reported enterocutaneous fistula rate for OAs has not been significantly different with NPWT compared with non-NPWT dressings [40]. Data from a large systematic review do not show any evidence of a relationship between use of NPWT and fistula formation [41]

Table 8 Late OA closure: outcomes and advanced indications for NPWT in OA for IAI

Pt. N	Sex, Age	Diagnosis and NPWT duration (days)		Late OA closure due to	Abdominal complications occurring during OA	Contraindications to / challenging situations with NPWT during long OA	Pressure lowered to 25–50 mmHg	Intermittent setting	Fistula guidance	Drain contaminants	OA + NPWT advanced indication
1	F, 45	Necrotizing-hemorrhagic pancreatitis post pancreatic rupture from Wirsung duct cannulation (mistaken for CBD) in choledocholithiasis; lap chole years before	> 21	FSC Infected pancreatic necrosis	Duodenal rupture (3 times) Hemorrhage EAF(duodenum, then ileum) Frozen abdomen Abdominal wall fixity New-onset bile. Pancr. leak	Duodenal suture repair Hemorrhage Bile leak EAF(duodenum, then ileum)	•	•	•	•	Active removal/diversion of fluid contaminants Fistula guidance Lengthier TAC for SC and frozen abdomen
2	F, 55	Acute bowel ischemia from volvulus, septic state	> 7 < 21	Planned relook for risk of: Recurrent ischemia Venous infarction	–	Concern for NPWT impacting on risk of new SBI	•				Lengthier TAC for planned relook
3	F, 67	Intra-abdominal abscess from jejunal fistula following hiPEC for peritoneal carcinomatosis (appendiceal cancer)	> 21	FSC Enteric fistula	Frozen abdomen	Peritoneal cancer Enteric fistula (bowel loop fixed deep in frozen abdomen)	•		•		Fistula guidance Lengthier TAC for SC and frozen abdomen
4	F, 30	Necrotizing-hemorrhagic pancreatitis	> 21	FSC Infected pancreatic necrosis	Hemorrhage Adhesive peritonitis	Hemorrhage	•	•			Lengthier TAC for source SC
5	M, 71	Intraabdominal abscess post jejunal anastomosis leakage	> 7 < 21	FSC Infected abdominal recess walled-off by dense adhesions	Frozen abdomen	Frozen abdomen	•			•	Lengthier TAC for SC and frozen abdomen
6	M, 74	Uroperitoneum post radical cystectomy	> 21	FSC Contamination from urine	Adhesive peritonitis	Existing bowel anastomosis fashioned during cystectomy	•			•	Active removal/diversion of fluid contaminants
7	F, 76	Deep SSI and mesh infection (previous repair of incisional hernia) in resected endometrial carcinoma	> 21	FSC Persistent peritoneal infection Infected mesh (with patient unfit for mesh removal)	Frozen abdomen	Peritoneal cancer Frozen abdomen		•			Lengthier TAC for SC and frozen abdomen
8	F, 74	Enteric leak after Rives repair of recurrent abdominal wall hernia	> 21	FSC Enteric fistula with bowel fixity not allowing stoma creation	Frozen abdomen	Enteric fistula Frozen abdomen	•		•		Fistula guidance Lengthier TAC for SC and frozen abdomen

Table 8 (continued)

Pt. N	Sex, Age	Diagnosis and NPWT duration (days)		Late OA closure due to	Abdominal complications occurring during OA	Contraindications to / challenging situations with NPWT during long OA	Pressure lowered to 25–50 mmHg	Intermittent setting	Fistula guidance	Drain contaminants	OA + NPWT advanced indication
9	M, 16	Rectum, ureter and urethra rupture from blunt truncal trauma	> 21	FSC Contamination of abdomen and pelvis from urine	Adhesive peritonitis	Multisite trauma Ruptured rectum, urethra Urine leak	•	•		•	Active removal/diversion of fluid contaminants Lengthier TAC for SC
10	F, 74	Intraabdominal abscess from perforation of colostomy limb; recent small bowel anastomosis	> 21	FSC Infected peritoneal surfaces	–	Pre-existing bowel anastomosis	•	•			Lengthier TAC for SC and planned relook

EAF, entero-atmpsoheric fistula; FSC, failure of source control (persistent infection or contamination); SC, Source control; IAI, severe intraabdominal infection; OA, open abdomen; NPWT, negative pressure wound therapy; SSI, surgical site infection; TAC, temporary abdominal closure

The preferred treatment for entero-atmospheric fistula is the restoration of gastrointestinal continuity at the time of the abdominal wall reconstruction. Success depends on the eradication of sepsis, optimizing nutrition status (albumin > 3.2 g/dL) during the management phase, and delaying operative repair of a minimum of 3 months to stage a deferred, elective gastrointestinal reconstruction when the patient's sepsis has resolved [42].

Goals of EAF management are the control fistula effluent to prevent contamination and protecting the surrounding tissue and granulation bed while maintaining patient nutrition and metabolic balance, to bridge to definitive surgical repair once the wound matures [28]. Enteral nutrition, preferred if feasible, otherwise, total parenteral nutrition (TPN), along with adequate antibiotic therapy have already been described as key measures to successfully manage EAF and enterocutaneous fistula [39, 43, 44].

Negative pressure dressings can be used to collect the enteric fluid to keep the open abdomen clean while and to isolate the fistula with custom barriers, so NPWT to be applied around but not on the fistula. NPWT was reported to be effective in the control of fistula effluent with eventual healing of the fistula [45].

Although surgical treatment has been documented as a far more effective form of management of EAF than conservative [43], access to the leaking bowel loop is necessary for surgical manipulation. In this study all cases of EAF occurred in a bowel segment that was either deep and fixed in the abdominal cavity (duodenum, ileum) or that was simply not visible as buried in a frozen abdomen. As the bowel opening was not visible, EAF was revealed only by enteric fluid trickling between the bowel mass and the abdominal wall from deep within the peritoneal cavity (Fig. 3), and fistula manifested through a leakage of intestinal fluid from one of the closed edges of the laparostomy wound overlying a frozen abdomen. In both cases of intestinal fistula in this study, NPWT with suction cap was positioned on one side of the laparotomy wound and provided significant aid by removing contamination and preventing wider spread, while high-calories/high-protein individualized parenteral nutrition was probably a key factor, allowing patients to wall off and slowly turn EAF into an enterocutaneous fistula that eventually closed in all participants.

Placing the NPWT suction cup on top of the area where leakage from an EAF occurred has been shown to contribute to avoid spillage and allow for the creation of a guided fistula through NPWT even when fistula-specific devices (eg. fistula crown) could not be directly used [44].

Using NPWT to treat conservatively an EAF has been previously described in challenging combinations of intestinal fistula and frozen abdomen, with the attempt at forming a controlled fistula while diverting

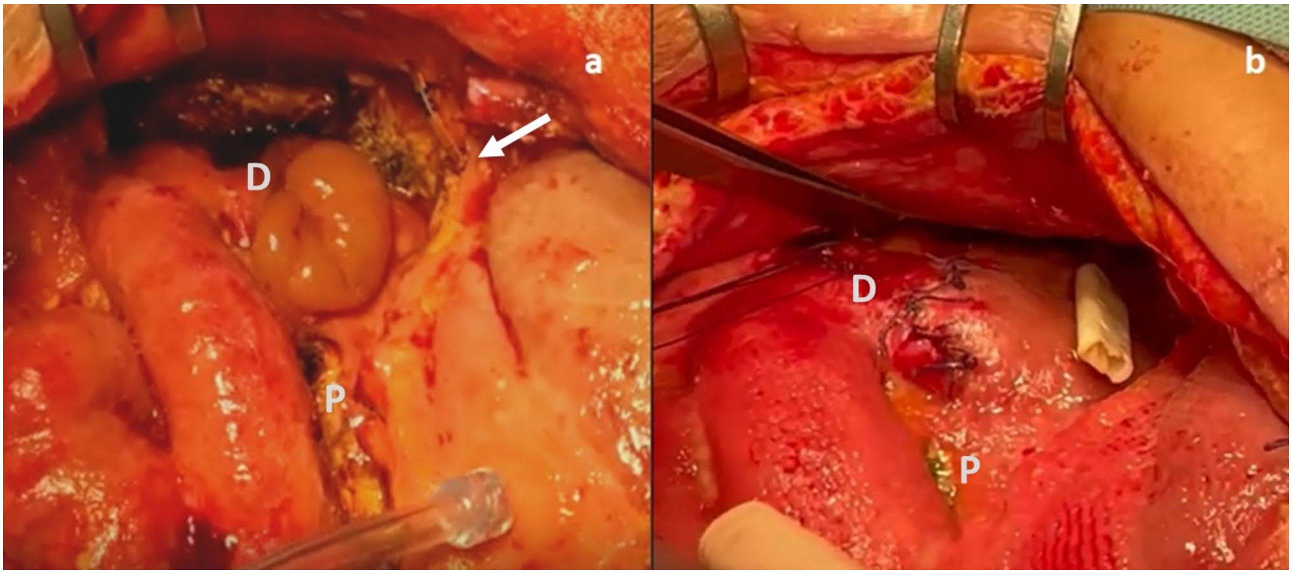

Fig. 2 Surgical treatment of duodenal perforation in a patient who developed severe necrotizing pancreatitis from iatrogenic pancreas perforation, due to an attempt at endoscopic cannulation of the common bile duct (CBD) for common bile duct stones, resulting in erroneous, initially occult cannulation of the Wirsung duct. The patient had undergone laparoscopic cholecystectomy 20 years prior to endoscopic attempt at CBD clearance, so during damage control surgery the stump of the cystic duct was cannulated to divert bile flow away from the CBD. When the patient woke up in the intensive care unit, bile flow through the cystic duct increased, exceeding the capacity of the transcystic catheter, and bile leak was observed leaking from the cystic duct stump, aside the transcystic catheter (Panel a—white arrow); the bile leaked from the cystic duct fell on the duodenum (white D letter), encountering pancreatic juice exuding from the disintegrated pancreatic head (white P letter), contributing to duodenal perforation. Surgical repair was performed on three distinct occasions, for three instances of duodenal perforation, each one of them in three distinct sites; Jackson Pratt (Panel b) drain was added to divert bile away from the duodenum. All sutures healed in the context of a dense peritoneal fibrotic reaction (frozen abdomen)

contamination and promoting clean granulation over the bowel [46]. This is also consistent with previous observations that NPWT was the best option available to treat Bjork Grade 3 OA with an EAF [41].

On the other hand, use of NPWT has been contraindicated in non-enteric and unexplored fistulae due to a mechanism of excessive fluid extraction which can lead to impaired fistula healing, increased output, with collateral dehydration and electrolyte imbalance [47].

We found that in these particular situations, lowering the intensity of NPWT preserved its properties as the ability to actively drain large effluent and that of providing adequate protection of the abdominal cavity from the outer ambient, which were functional to the resolution of the patient's clinical picture: stable diversion of contaminants in the forms of ostomy (nephrostomy, colostomy) or percutaneous drainage (eg to address bile leak) were realized as soon as the patient's condition permitted.

During long OA, we found that in nearly all patients the negative pressure was set to a lower intensity, down to 25–50 mmhg; in many cases treatment mode was also set to intermittent application of negative pressure to limit the impact to serosal surfaces; this level of pressure has been previously suggested as safe while managing complex conditions as bleeding or enteric fistulas [28, 48]. The latest WSES guidelines for the management of the OA also recommend lowering the negative pressure regime as a mean to prevent or tackle NPWT specific complications arising during OA [6].

Still, there are only few clinical series or controlled trials supporting the idea that adjusting the variables of NPWT treatment may minimize or help manage complications such as ischemia and pain, and optimize outcome [30].

It is important to control, not only at admission but throughout the OA therapy, fluid resuscitation, local and systemic inflammatory response and sepsis, all conditions that can precipitate patient towards multiple organ failure, knowing that ideal timing for abdominal closure after TAC is when a patient of adequate nutritional status is stable and the distance between the fascial edges is within 7 cm [49].

Strength of this study is that it has been conducted in a large series of consecutive cases, where all patients were treated by the same protocol and goal-directed approach that included high calories/high protein nutritional support, antibiogram-guided antibiotic therapy, consistent 48–72 h interval between VAC dressing change and weekly multidisciplinary case review as a minimum common denominator.

This study has also several limitations, owing in first instance to its retrospective design and the inevitable selection bias connected to it, though data from these cases were collected prospectively ahead of this study.

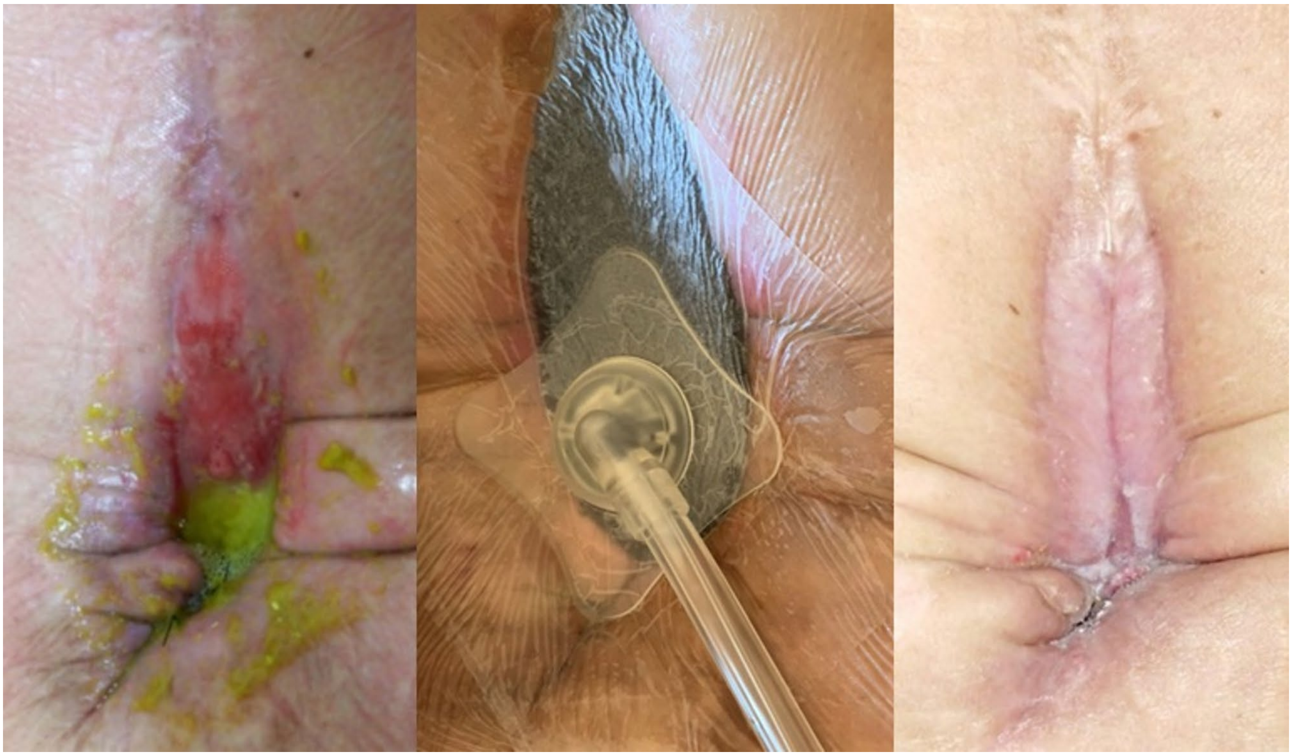

Fig. 3 Enteroatmospheric fistula(EAF) manifesting two months after index operation, from the depth of a frozen abdomen (source of enteric fluid not visible); NPWT suction cap was placed over observable outflow of enteric fluid, pressure was reduced to 25 mmHg and intermittent setting was chosen to divert enteric fluid away from the frozen abdomen. EAF eventually healed in one further month with high calories-high protein total parenteral nutrition as a background and carefully balanced, light soft diet

Data were obtained from a single -though large- center, with a number of patients in the study group that may be too low to obtain generalizable results. Differences in the distribution of comorbidities, nutritional status and severity of the underlying disease may have influenced outcomes, though multivariable analysis was run to control for confounding.

One of the other considerations in this study is the risk to overemphasize the role of NPWT in the successful management of patients with OA, in particular those with long OA. This is mainly due to the absence of a control group for OA with NPWT, as NPWT was the only option used for temporary abdominal closure.

Despite these limitations, evidence from this study supports NPWT as a key modality for delivering an individualized approach to complex and heterogeneous cases. NPWT allows for stage-specific interventions, including wound and fluid management, while facilitating primary fascial closure. Given that all surviving patients who underwent late closure of the OA benefited from the targeted application of specific NPWT properties to achieve favorable outcomes, the evidence from this study suggests that complex anatomical and pathological conditions associated with late OA closure may constitute advanced indications for the use of NPWT in OA management for IAI.

The impact on outcomes of specific adjustments to NPWT parameters—such as reducing the level of negative pressure—warrants further investigation to determine whether NPWT represents a viable strategy for managing prolonged open abdomen cases requiring multiple re-explorations, particularly in scenarios where alternative techniques are not feasible from the patient's clinical standpoint.

Conclusion

NPWT appears to be a safe and reliable therapeutic option for critically ill patients with severe abdominal sepsis. NPWT in OA for IAI may contribute to high rates of overall fascia closure, especially when the abdomen is closed within a week from OA creation. Patient and disease factors impacted on mortality and, indirectly through prolonged OA duration, on the development of serious complications, while the duration of OA did not directly impact on survival. Longer OA and late closure were significantly associated to lower rates of primary fascial closure and increased rate of serious complications as EAF and frozen abdomen. In patients surviving to achieve the opportunity of late closure, NPWT specific properties may be leveraged to handle high-risk clinical scenarios, as EAF management, frozen abdomen and persistently contaminated abdomen, which are advanced

Table 9 Björk classification of ten patients who completed hospital admission following late closure of the OA

	Grade		Late closure OA
OA (Björk) classification at first relook	1	A	22%
		B	–
		C	11%
	2	A	11%
		B	22%
		C	11%
	3	A	–
		B	11%
	4		22%
OA (Björk) classification at OA closure	1	A	22%
		B	–
		C	–
	2	A	33%
		B	–
		C	–
	3	A	44%
		B	–
	4		11%

Björk classification: Grade 1A- Clean OA without adherence between bowel and abdominal wall or fixity; Grade 1B- Contaminated OA without adherence/fixity; Grade 1C- Enteric leak, no fixation; Grade 2A- Clean OA developing adherence/fixity; Grade 2B- Contaminated OA developing adherence/fixity; Grade 2C- Enteric leak, developing fixation; Grade 3A- Clean, frozen abdomen; Grade 3B- Contaminated, frozen abdomen; Grade 4- Established enteroatmospheric fistula, frozen abdomen

OA, open abdomen; IAI, intra-abdominal infection; PI, pelvic infection; CCI, Charlson Comorbidity Index; CFS, Clinical Frailty Scale; APACHE II, Acute Physiologic Assessment and Chronic Health Evaluation; ASA, American Society of Anesthesiology; MPI, Mannheim Peritonitis Index; OS, Overall perioperative (30-days) survival; WBC, White blood cell count

indications of NPWT, extending beyond temporary abdominal closure. The management of patients with late closure of the OA in this study shows that while the basic role of NPWT in temporary abdominal closure is well-established, advanced indications are less clearly defined in clinical practice. Prospective, multicentre studies are necessary to gain a clearer understanding of NPWT's role in advanced indications, to guide surgical decision-making, improve fascial closure rates, and reduce complications such as EAF and mortality in septic patients.

Author contributions

FPP Concept and design of the study; acquisition, analysis of data and literature review, draft writing, manuscript editing and review GMDL Concept and design of the study; acquisition, analysis and review of data, draft writing LIS Critical review, literature review EP Analysis and review of data, draft writing SM Draft writing, literature review GRP literature review, acquisition of data MM acquisition of data, literature review BS, draft writing, manuscript review LM Critical review, manuscript review AGu analysis of data, draft writing, manuscript review Fco Critical review, manuscript review Fca Critical review, manuscript review MT Coordination of the study, draft writing, manuscript review, intellectual input. All the authors read and approved the final manuscript.

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Data availability

The data are available on request to the corresponding author.

Declarations

Ethics approval and consent to participate

The methodology of this study has been reviewed by the Institutional Review Board of Policlinico di Bari University Hospital and ethical approval was granted (UniBa prot.n.7870/25). All procedures in this study were conducted in accordance with the ethical standards of the declaration of Helsinki. Informed consent was obtained from all participants.

Consent for publication

Patient consent for research use of individual data was obtained for each case presented. All identification data of the patients were removed from medical records prior to data collection. De-identified data were used, and it was not possible to trace any of the data to the actual individual. Only information required for coherent description of cases was extracted. Data in electronic format were accessible to authorized personnel only. Consent was given for the publication of intraoperative pictures.

Competing interests

All authors declare no competing financial or non-financial interests.

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