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SCIENTIFIC REVIEW

Systematic Review and Meta-analysis of the Open Abdomen and Temporary Abdominal Closure Techniques in Non-trauma Patients

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Abstract

Background Several challenging clinical situations in patients with peritonitis can result in an open abdomen (OA) and subsequent temporary abdominal closure (TAC). Indications and treatment choices differ among surgeons. The risk of fistula development and the possibility to achieve delayed fascial closure differ between techniques. The aim of this study was to review the literature on the OA and TAC in peritonitis patients, to analyze indications and to assess delayed fascial closure, enteroatmospheric fistula and mortality rate, overall and per TAC technique.

Methods Electronic databases were searched for studies describing the OA in patients of whom 50 % or more had peritonitis of a non-traumatic origin.

Results The search identified 74 studies describing 78 patient series, comprising 4,358 patients of which 3,461 (79 %) had peritonitis. The overall quality of the included studies was low and the indications for open abdominal management differed considerably. Negative pressure wound therapy (NPWT) was the most frequent described TAC technique (38 of 78 series). The highest weighted fascial closure rate was found in series describing NPWT with continuous mesh or suture mediated fascial traction (6 series, 463 patients: 73.1 %, 95 % confidence interval 63.3–81.0 %) and dynamic retention sutures (5 series, 77 patients: 73.6 %, 51.1–88.1 %). Weighted rates of fistula varied from 5.7 % after NPWT with fascial traction (2.2–14.1 %), 14.6 % (12.1–17.6 %) for NPWT only, and 17.2 % after mesh inlay (17.2–29.5 %).

Conclusion Although the best results in terms of achieving delayed fascial closure and risk of enteroatmospheric fistula were shown for NPWT with continuous fascial traction, the overall quality of the available evidence was poor, and uniform recommendations cannot be made.

Introduction

Several challenging clinical situations can necessitate leaving the abdominal cavity open after surgery, resulting in an open abdomen (OA) or laparostoma. Excessive visceral edema, seen in severe abdominal sepsis, may prevent successful tension-free fascial closure after laparotomy, forming an inescapable indication for the OA. It may also be necessary to leave the abdomen open following a decompression laparotomy for abdominal compartment syndrome (ACS). Furthermore, the OA can be part of damage control surgery and other strategies involving a planned relaparotomy, such as second-look operations for intestinal ischemia.

Many techniques for temporary abdominal closure (TAC) of an OA have been described. Besides prevention of evisceration, TAC can facilitate regaining access to the

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abdominal cavity (in case necessary) and prevents retraction of skin and fascia. Ideally, it enables postponed fascial closure of the abdominal cavity, i.e., delayed primary fascial closure.

Whether or not an OA is needed, and the possibility of successful outcomes after TAC highly depends on the underlying condition. Success rates of delayed fascial closure are lower in non-trauma patients compared to trauma patients, and several studies identified peritonitis as an independent predictor of failure of fascial closure [1–3]. Furthermore, the applied indications for open abdominal management differ between trauma patients and patients with peritonitis, and also influence the possibility of achieving delayed fascial closure. Moreover, one of the most feared complications of the OA, formation of enteroatmospheric fistula, is associated with the etiology of OA; high rates of fistula formation have been described in patients with an OA due to peritonitis [2]. The concern of fistula formation especially regards the use of negative pressure wound therapy (NPWT), which has become an increasingly popular technique of TAC [4–6].

The objective of this study was to systematically review the literature on the OA and TAC in peritonitis patients only, to analyze indications and to assess delayed fascial closure, enteroatmospheric fistula and mortality rate, overall and per TAC technique.

Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guideline [7].

Literature search

A systematic literature search was performed in Medline (PubMed), EMBASE (Ovid), and the Cochrane Central Register of Controlled Trials on 3 January 2014 to identify studies describing the OA and TAC in patients with (secondary) peritonitis. The search strategy was constructed in consultation with a clinical librarian. Search terms related to open abdominal management and TAC techniques were used (refined Medline search is listed in Online Appendix 1). No restrictions regarding language or publication date were applied. Bibliographies of all included articles and relevant review papers were searched manually for additional relevant articles. Titles and abstracts were screened by two authors (JJA, SLG) independently. Disagreement on relevance was addressed by discussion and consensus. Subsequently, full-text articles were retrieved and read by both authors.

Study selection

To be eligible for inclusion, studies had to describe the OA and TAC in patients with peritonitis of non-traumatic origin. Studies including OA patients with various etiologies were included if more than 50 % of the described patients had an AO due to peritonitis, or if data concerning peritonitis patients could be derived separately. Furthermore, studies had to provide information about the applied TAC technique and had to report on at least two of the following outcomes of interest: delayed fascial closure rate, enteroatmospheric fistula rate and mortality. Only articles of which the full text was written in English, German, Spanish, or Dutch were included. Review articles, opinion papers, case reports (<5 patients), pediatric series, series with other than midline incisions, animal and laboratory studies and studies including $\leq$50 % peritonitis patients or studies not reporting results for peritonitis patients separately were excluded. If multiple articles reported on the same patient population, only one study was included based on relevance and population size. In case articles described separate patient series based on underlying conditions, all series fulfilling the inclusion criteria were included separately. Studies including both patients with an OA and patients undergoing closed abdominal management were only considered for inclusion if separate data were available for patients with an OA.

Definitions

Peritonitis as underlying disease was defined as open abdominal management commenced after an operation indicated by an intra-abdominal source of infection, such as anastomotic leakage, gastrointestinal perforation, necrotizing pancreatitis, or bowel ischemia. Patients undergoing an index operation for trauma, despite the possible development of peritonitis following traumatic bowel injury or postoperative complications, were considered trauma patients and were thus excluded. Patients undergoing open abdominal treatment after operations for hemorrhage, including ruptured abdominal aortic aneurysms, or loss of fascial domain (traumatic or caused by fasciitis) were excluded. Patients with an OA after full-thickness dehiscence postoperatively were considered for inclusion only if the primary operation was performed for peritonitis.

Delayed primary fascial closure was defined as achieving complete midline closure of the fascia (without a mesh) during the index admission. TAC techniques were categorized based on the definitions described by Boele van Hensbroek et al. (Table 1) [3]. The category 'Vacuum-assisted closure (VAC^{TM})' was extended to 'Negative-pressure wound therapy (NPWT)' and included all closure techniques applying negative pressure to the fascial edges

Table 1 Description of temporary abdominal closure techniques

TAC Technique	Description
NPWT	A perforated plastic sheet is positioned to cover the intestine, a polyurethane sponge, or damp surgical towels/pads are placed on top, between the fascial edges. The wound is covered with an airtight seal and is centrally pierced by a suction drain, which is connected to a pump and fluid collection system. Self-made variations of this technique (using towels/gauzes) are commonly referred to as Barkers' "Vacuum Pack". Commercial available systems include VAC Abdominal Dressing (KCI), Renasys NPWT (S&N), Avance (Mölnlycke), and ABThera Open Abdomen Negative Pressure Therapy System (KCI)
NPWT with continuous fascial traction	Modification of NPWT, using a mesh or sutures sutured to the fascial edges, which can be tightened with every NPWT system change
Dynamic Retention Sutures	Extraperitoneally placed large, non-absorbable sutures through all layers of the abdominal wall, including the skin. Sutures can be gradually tightened. May be combined with a NPWT system. Commercial available systems include ABRA Abdominal Wall Closure System (Canica Design)
Wittmann patch ('artificial burr')	Two Velcro pieces are sutured to the fascial edges and facilitate gaining access to the abdominal cavity and gradual re-approximation of the abdominal wall. May be combined with a NPWT system
Bogota bag	A sterile irrigation bag is sutured between the fascial edges. It can be reduced in size to approximate the fascial edges
Mesh	An absorbable or nonabsorbable mesh is sutured between the fascial edges (usually 'inlay'). The mesh can potentially be tightened gradually. Non-absorbable meshes can be removed or left in place
Zipper	A mesh with a zipper is sutured between the fascial edges. It is comparable to mere mesh placement but allows for a more easy access to the abdominal cavity
Loose packing	The fascial defect is covered by standard wound dressing

TAC temporary abdominal closure, *NPWT* negative pressure wound therapy

(including the 'Vacuum pack'). A separate category was created for techniques combining negative pressure with continuous suture- or mesh-mediated fascial traction. Indications for the OA were categorized as follows: inability to close (due to excessive edema), part of a planned relaparotomy strategy, part of an imperative relaparotomy (second look for intestinal ischemia or damage control surgery), documented intra-abdominal hypertension (IAH) or ACS, and abdominal cavity drainage for severe intra-abdominal infection. If the provided indication did not fall into one of the aforementioned categories, the indication was listed as literally given in the article (between quotation marks). Studies reporting retrospective analyses of prospectively gathered data were considered prospective.

Data extraction

Data were extracted independently by two authors (JJA, SLG) using a predefined data sheet. The extracted data included study characteristics (first author, year of publication, inclusion period, type of study design), patient characteristics (number of included subjects, underlying etiology, indications for open abdominal management, the Acute Physiology and Chronic Health Evaluation II score, Mannheim Peritonitis Index, number of constructed bowel anastomoses at the index laparotomy or possible relaparotomies (excluding anastomoses combined with deviating ileostomies)), details regarding the applied TAC technique and the following outcome measures; delayed fascial closure rate, enteroatmospheric fistula rate, and in-hospital mortality. Delayed primary fascial closure rate was calculated by dividing the number of patients in whom the fascia could be completely closed during admission, by the total number of included patients. If no apparent intention to achieve delayed fascial closure was described, the fascial closure rate was considered to be not available instead of zero. The number of events of various outcomes was registered as zero only when it was clearly specified in the article. For studies comparing different techniques of TAC or different patient groups, results were calculated per technique/patient group.

Methodological quality assessment

The methodological quality of all included articles was assed. The five-point Jadad score was used for quality assessment of randomized comparative studies [8]. For non-randomized observational studies, the nine-point Newcastle–Ottawa Scale was used [9]. Because one item on this nine-point scale was considered irrelevant regarding the subject of this systematic review ("demonstration that outcome of interest was not present at start of study"), the maximum score was eight instead of nine.

Statistical analysis

Data were analyzed per category of TAC technique. We calculated a weighted average of the logit proportions by the use of the generic inverse variance method and back-

transformed the summary estimate and 95 % confidence interval (CI) to obtain a summary proportion. If the combined number of patients was 20 or less, no pooled weighted average was calculated. Random effects estimates were used to test the variation between different studies. Heterogeneity was assed using the χ^2 and I^2 statistics and was considered significant (considerable heterogeneity) if p value <0.1 and $I^2 > 75$ %. Analysis was performed using Review Manager 5.2 (The Cochrane Collaboration; Copenhagen, Denmark).

Results

Included studies

The process of the study selection is summarized in Fig. 1. The initial search identified a total of 1,528 articles. After screening the titles and abstract, 222 articles were considered for inclusion and full-text manuscripts were retrieved. Of these, another 148 articles did not meet the inclusion criteria. The remaining 74 articles were included in this review, published between 1983 and 2013. Study characteristics and outcomes are shown in Table 2, and details are listed in Online Appendix 2. In total, one randomized trial, 19 prospective studies, 53 retrospective studies, and 1 non-specified study were included.

In total, from the 74 studies, 78 separate series of patients were included. Five of the included studies compared two TAC techniques [10–14]. Of one of these studies, only one arm fulfilled the inclusion criteria and was included [11]. Of the remaining four studies, both groups were included as separate patient series [10, 12–14]. Seven studies compared the OA between different patient series based on etiology [1, 15–20]. One study compared three groups (trauma, sepsis, and pancreatitis) of which two groups fulfilled the inclusion criteria (sepsis and pancreatitis); these patients were included as one group [1]. Of the other six studies comparing different patient populations, only one separate series of patients from each study fulfilled the inclusion criteria and was included [15–20]. Three studies included both patients with an OA and

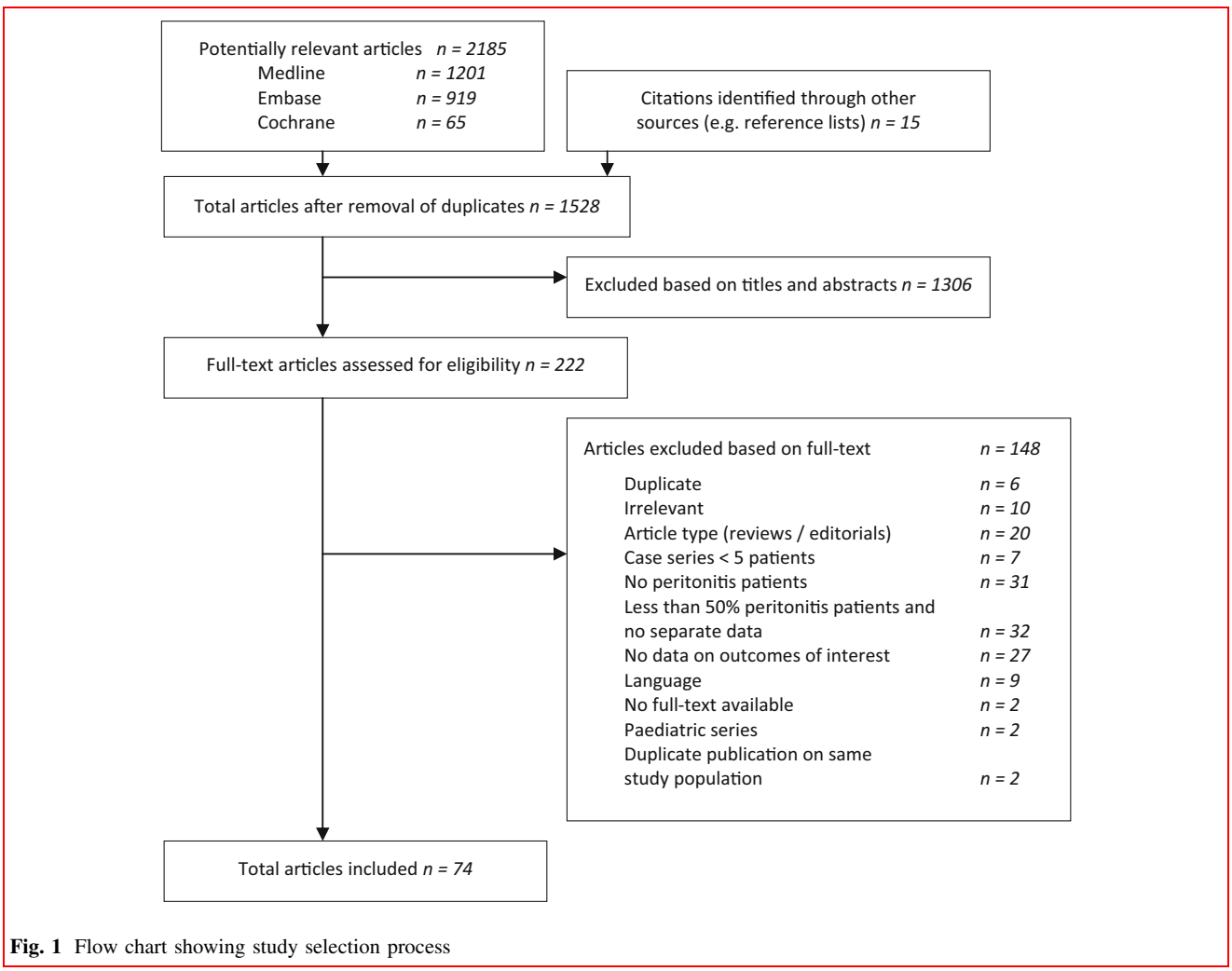

Fig. 1 Flow chart showing study selection process

Table 2 Summarized characteristics and outcomes of 74 included studies combining for 78 patient series (details are listed in Online Appendix 2)

Reference	Year	Study design	No. of patients[a]	Peritonitis etiology (%)	Indication	TAC technique	Fascial closure (%)	Fistula (%)	Mortality (%)	NOS
Bertelsen et al. [87]	2013	Retrospective	101	83.1	46.6 % DFI, 25.7 % II, 23.7 % ITC, 4.0 % "fascial necrosis"	NPWT	39.6	2.0	39.6	5
Carlson et al. [10]	2013	Prospective	355	72.9	Unclear	NPWT	41.1	13.8	27.3	4
			223	66.3		Various	60.1	8.5	29.6	
Fortelny et al. [30]	2013	Prospective	87	100.0	DFI	NPWT with fascial traction	78.2	3.4	26.4	5
Goussous et al. [15]	2013	Retrospective	79 (of 111)	81.0	31 % "Loss of domain", 30 % II, 25 % "faecal contamination", 14 % "hemorrhage"	Various	58.2	7.6	19.0	3
Haddock et al. [52]	2013	Retrospective	36	61.1	DCS	DRS	83.3	0.0	2.8	5
Huang et al. [71]	2013	Retrospective	40	60.0	55.0 % ITC, 22.5 % IAH/ACS, 12.5 % DFI, 10.0 % II	NPWT with fascial traction	60.0	25.0	na	4
Khan et al. [53]	2013	Retrospective	42	54.8	DCS	NPWT	73.8	9.5	19.0	4
Pliakos et al. [39]	2013	Prospective	39	100.0	"Sequential Organ Failure Assessment score >7 or Mannheim peritonitis score >29"	NPWT	59.0	0.0	35.9	5
Richter et al. [68]	2013	Retrospective	81	>60.5	Unclear	NPWT	80.2	16.4	30.9	5
Zielinksi et al. [66]	2013	Retrospective	18	73.7	39 % II, 33 % "Shock", 17 % PR, 6 % ITC	NPWT	83.3	0.0	11.1	5
Dietz et al. [43]	2012	Retrospective	62	53.2	PR	Other	33.9	4.8	40.3	3
Goussous et al. [82]	2012	Retrospective	173	63.6	33 % II, 31 % "Fecal contamination", 23 % "Loss of domain", 13 % "Hemorrhage"	Various	64.2	6.3	22.6	5
Kafka-Ritsch et al. [69]	2012	Prospective	160	93.8	"Advanced peritonitis >1 quadrant, patients requiring rapid wound closure", PR, ACS, ITC	NPWT with fascial traction	75.6	3.1	20.6	5
Kafka-Ritsch et al. [34]	2012	Prospective	51	100.0	DCS	NPWT with fascial traction	100.0	0.0	9.8	4
Kleif et al. [35]	2012	Retrospective	14 (of 16)	100.0	DCS	NPWT with fascial traction	50.0	0.0	7.1	5
Perez Dominquez et al. [61]	2012	Retrospective	23	78.3	Unclear	NPWT	78.3	17.4	26.1	3
Plaudis et al. [62]	2012	Prospective	22	72.7	ACS and/or PR	NPWT	100.0	13.6	4.5	5
Pliakos et al. [12]	2012	Prospective	31	100.0	Unclear	Various	16.1	54.8	45.2	4
			27	96.3		NPWT	66.7	0.0	37.0	

Table 2 continued

Reference	Year	Study design	No. of patients[a]	Peritonitis etiology (%)	Indication	TAC technique	Fascial closure (%)	Fistula (%)	Mortality (%)	NOS
Rasilainen et al. [11]	2012	Retrospective	54 (of 104)	61.1	59 % ACS, 31 % ITC, 7 % "prophylactic (for IAH)", 2 % IAH	Various	44.4	18.5	33.3	5
Salman et al. [76]	2012	Retrospective	7	85.7	Unclear	DRS	85.7	0.0	14.3	3
Acosta et al. [70]	2011	Prospective	111	51.4	69.4 % ITC, 26.1 % DFI, 19.8 % IAH/ACS, 12.6 % II	NPWT with fascial traction	76.6	7.2	29.7	5
Caro et al. [56]	2011	Retrospective	46	67.4	"Anticipated high risk of developing IAH/ACS; intestinal edema or difficulty to close"	NPWT	21.7	17.4	32.6	3
Fieger et al. [57]	2011	Retrospective	82	95.0	Unclear	NPWT	42.7	19.5	11.0	3
Manterola et al. [49]	2011	Prospective	86	64.0	PR	Bogota bag	39.5	12.8	11.6	5
Prichayudh et al. [20]	2011	Retrospective	19 (of 73)	78.9	"Primary closure impossible or dangerous"	NPWT	10.5	31.6	na	4
Verdam et al. [77]	2011	Retrospective	18	83.3	Unclear	DRS	77.8	16.7	11.1	5
Kritayakirana et al. [19]	2010	Retrospective	35 (of 103)	51.4	II, DFI, PR, DCS, IAH, "necrotizing abdominal wall infection"	NPWT	60.0	17.1	31.4	5
Lopez-Quintero et al. [37]	2010	Retrospective	19	100.0	"2 or more of the following: [1] fecal or diffuse peritonitis and difficult to manage with 1 operation, [2] hemodynamic instability, [3] excessive intestinal edema, [4] septic shock, [5] need for reassessment of anastomoses and [6] APACHE II score >15"	NPWT	36.8	26.3	26.3	5
Padalino et al. [38]	2010	Prospective	9	100.0	PR and ACS	NPWT	66.7	11.1	0.0	5
Schmelze et al. [41]	2010	Retrospective	49	100.0	Unclear	NPWT	22.4	22.4	40.8	4
Shaikh et al. [63]	2010	Prospective	42	76.2	40.5 % ITC, 59.5 % "thought unwise to close"	NPWT	52.4	4.8	9.5	5
Amin et al. [25]	2009	Prospective	20	100.0	PR	NPWT	65.0	10.0	0.0	5
Balentine et al. [88]	2009	Retrospective	88	62.5	33.0 % DFI, 17.0 % PR, 15.9 % II, 10.2 % ITC, 9.1 % IAH/ACS, 11.4 % "hemodynamic instability"	Various	38.6	12.5	34.1	5
Gonullu et al. [31]	2009	Retrospective	37	100.0	DFI, IAH	Bogota bag	13.5	10.8	43.2	3
Horwood et al. [58]	2009	Prospective	27	96.3	ITC, DCL, IAH/ACS	NPWT	18.5	11.8	37.0	5

Table 2 continued

Reference	Year	Study design	No. of patients[a]	Peritonitis etiology (%)	Indication	TAC technique	Fascial closure (%)	Fistula (%)	Mortality (%)	NOS
Özgüc et al. [59]	2008	Retrospective	74	78.4	50.0 % IAH/ACS, 43.2 % PR, 6.8 % DCS	NPWT	44.6	0.0	60.8	5
Reimer et al. [40]	2008	Retrospective	10 (of 23)	100.0	Unclear	DRS	30.0	20.0	0.0	3
Wondberg et al. [42]	2008	Prospective	30	100.0	PR, ITC	NPWT	33.3	6.7	30.0	5
Barker et al. [16]	2007	Retrospective	120 (of 258)	68.3	65.0 % PR, 12.5 % ITC, 8.3 % DCS,6.7 % IAH/ACS, 7.5 % "multifactorial"	NPWT	60.8	6.7	23.3	5
Kirshtein et al. [46]	2007	Retrospective	152	89.5	PR	Bogota bag	na	5.9	23.7	3
Perez et al. [60]	2007	Prospective	37	56.8	"High tension on the fascia, persistent bacterial contamination of the abdominal cavity, and massive bowel edema"	NPWT	70.3	2.7	37.8	5
Rao et al. [5]	2007	Retrospective	29	100.0	69.0 % DFI, 17.2 % ITC, 13.8 % IAH/ACS	NPWT	na	20.7	34.5	5
Robledo et al. [22]	2007	Randomized Controlled Trial	20 (of 40)	100.0	DFI	Mesh	na	10.0	55.0	3[b]
Wilde et al. [65]	2007	Retrospective	11	90.9	54.5 % "High risk for of IAH/ACS", 36.4 % PR, 9.1 % IAH/ACS	NPWT	90.9	18.2	0.0	3
Oetting et al. [17]	2006	Retrospective	22 (of 36)	100.0	PR	NPWT	68.2	13.6	22.7	3
Cipolla et al. [29]	2005	Retrospective	5 (of 17)	100.0	ITC	NPWT	20.0	20.0	0.0	3
Adkins et al. [24]	2004	Retrospective	81	100.0	Unclear	NPWT	na	14.8	33.3	5
García Iñiguez et al. [14]	2004	Retrospective	50	92	Unclear	Bogota bag	na	6.0	36.0	7
			50	96		Mesh	na	20.0	48.0	
Martinez-Ordaz et al. [13]	2004	Retrospective	21	100.0	"High risk for of IAH/ACS"	Bogota bag	na	28.6	38.1	3
			18	100.0		Other	na	5.6	38.9	
Tsuei et al. [1]	2004	Retrospective	46 (of 71)	93.5	Unclear	NPWT	15.2	19.6	39.1	3
Schachtrupp et al. [72]	2002	Unclear	40	70.0	Unclear	Mesh	57.5	na	25.0	3
Sokmen et al. [73]	2002	Retrospective	25	88.0	Unclear	Mesh	na	4.0	16.0	5
Doyon et al. [74]	2001	Retrospective	17	82.4	ITC, PR, DFI	Bogota bag	94.1	0.0	17.6	3
Koniaris et al. [36]	2001	Retrospective	6 (of 13)	100.0	Unclear	DRS	83.3	na	33.3	5
Tremblay et al. [18]	2001	Retrospective	50 (of 118)	92.0	32 % ITC, 24 % PR, 14 %, DCS, 12 % ASC, 18 % other	Various	12.0	14.0	56.0	5
Zingales et al. [50]	2001	Retrospective	60	91.7	PR	Zipper	20.0	13.3	38.3	3
Bailey et al. [27]	2000	Retrospective	7	100.0	DFI	Various	14.3	14.3	28.6	3

Table 2 continued

Reference	Year	Study design	No. of patients[a]	Peritonitis etiology (%)	Indication	TAC technique	Fascial closure (%)	Fistula (%)	Mortality (%)	NOS
Bosscha et al. [28]	2000	Retrospective	67	100.0	PR	NPWT	28.4	23.9	41.8	3
Tons et al. [51]	2000	Retrospective	377	67.0	ACS	Mesh	18.0	18.0	21.5	3
Wittmann et al. [78]	2000	Prospective	128	85.0	PR; 87 % ITC, 13 % II	Wittmann patch	93.0	2.3	18.8	3
Gentile et al. [23]	1998	Retrospective	11 (of 40)	100.0	PR	Mesh	na	54.5	45.5	4
Losanoff et al. [47]	1997	Retrospective	19	89.5	PR	Other	78.9	0.0	21.1	3
Losanoff et al. [48]	1997	Retrospective	29	72.4	PR	Mesh	79.3	0.0	20.7	3
Smith et al. [64]	1997	Retrospective	38 (of 93)	84.2	PR, ITC, II, DCS, ACS, DFI	NPWT	55.3	na	42.1	5
Brock et al. [55]	1995	Retrospective	11 (of 28)	90.9	81.8 % PR, 9.1 % IAH/ACS, 9.1 % both	NPWT	18.2	36.4	36.9	5
Hubens et al. [33]	1994	Retrospective	23	100.0	PR	Zipper	34.8	na	39.1	3
Ercan et al. [75]	1993	Retrospective	10	90.0	Unclear	Zipper	60.0	0.0	40.0	3
Hakkiluoto et al. [32]	1992	Prospective	21	100.0	PR	Zipper	na	0.0	47.6	3
Schein et al. [21]	1991	Prospective	31 (of 52)	100.0	PR	Mesh	3.2	na	58.1	3
Wittmann et al. [79]	1990	Prospective	117	94.9	PR and DFI	Various	na	00.0	23.9	3
Ivatury et al. [45]	1989	Retrospective	30	56.7	PR	Various	na	10.0	46.7	3
Hedderich et al. [44]	1986	Retrospective	10	80.0	PR	Zipper	na	20.0	20.0	3
Anderson et al. [26]	1983	Retrospective	20	100.0	DFI	Loose packing	55.0	25.0	60.0	3
Hollender et al. [54]	1983	Retrospective	22	90.9	DFI	Loose packing	na	0.0	31.8	3

TAC temporary abdominal closure, *NOS* Newcastle–Ottawa Scale, *na* not available, *ITC* inability to close, *II* second look for intestinal ischemia, *PR* planned relaparotomy, *DCS* damage control surgery, *DFI* drainage for intra-abdominal infection, *IAP* intra-abdominal pressure, *IAH* intra-abdominal hypertension, *ACS* abdominal compartment syndrome, *NPWT* negative pressure wound therapy, *DRS* dynamic retention sutures

[a] Number of patients included in this review and analysis. If a subset of the patients reported in the original article was included, the total number of patients described in the original article is given between parentheses

[b] Jadad score

Table 3 Weighted percentage of patients with an etiology of peritonitis, delayed primary fascial closure, enteroatmospheric fistula, and mortality per temporary abdominal closure technique

TAC technique	Series *n*	Patients *n*	Peritonitis etiology		Fascial closure		Fistula		Mortality	
			%	(95 % CI)	%	(95 % CI)	%	(95 % CI)	%	(95 % CI)
NPWT	32	1,627	82.8[a]	(77.5–87.0)	51.5[a,b]	(46.6–56.3)	14.6[a]	(12.1–17.6)	30.0[a]	(25.6–34.8)
NPWT with fascial traction	6	463	90.3[a,b]	(69.6–97.4)	73.1[a]	(63.3–81.0)	5.7[a,b]	(2.2–14.1)	21.5[a]	(15.2–29.5)
Mesh	8	583	84.6[a,b]	(72.9–91.8)	34.2[a,b]	(9.7–71.5)	17.2[a]	(9.3–29.5)	34.4[a,b]	(23.0–48.0)
Bogota bag	6	363	88.5[a,b]	(74.1–95.4)	47.0[a,b]	(14.1–82.7)	10.4[a]	(5.9–17.8)	27.1[a]	(18.0–38.6)
Zipper	5	124	92.9	(85.3–96.8)	34.0[a]	(16.7–56.9)	12.5	(7.0–21.2)	39.1	(30.8–48.0)
Dynamic retention sutures	5	77	80.1	(60.7–91.2)	73.6	(51.1–88.1)	11.6	(4.5–26.9)	11.1	(4.5–25.0)
Loose packing	2	42	96.6	(84.2–99.3)	na		15.7	(7.4–30.4)	40.0[a]	(25.5–56.5)
Wittmann patch[c]	1	128	85		119		3		24	

TAC temporary abdominal closure, *NPWT* negative pressure wound therapy, *na* not applicable (combined number of patients ≤20)

[a] $\chi^2 < 0.1$

[b] $I^2 > 75$ %

[c] Actual numbers given instead of percentages

patients undergoing closed abdominal management; only patients with an OA were included [21–23]. The remaining 59 articles described the OA in, amongst others, peritonitis patients without comparing types of TAC technique or etiology.

Methodological quality of included study

The methodological quality of the only randomized trial scored 3 points on the Jadad scale [22]. Regarding the remaining studies, the methodological quality was assessed using the Newcastle–Ottawa Scale (maximum score 8 points); thirty-two studies scored 3 points, eight studies 4 points, thirty-two studies 5 points, and one study was awarded 7 points. Details regarding methodological quality assessment are listed in Online Appendix 3.

Patients

Overall, 4,358 patients were included in this review, of which 3,461 (79 %) had (secondary) peritonitis. Of the 78 included series of patients, 27 comprised solely patient with peritonitis; data of a total of 505 patients (range 7–81 patients per publication) were available [5, 12, 13, 17, 21–42]. Eight series included OA patients with different etiologies. Here, data of 119 patients with peritonitis could be derived separately (range 5–31 patients per publication) [17, 21–23, 29, 35, 36, 40]. The remaining 43 series comprised patients of which more than half had peritonitis as underlying disease (range 51.4–96.3 % of 7–259 patients). From these 43 series data from 3,734 patients were included.

In 63 of 78 series (81 %) the sex distribution was described. The percentage of female patients ranged from 5.7 to 72.7 %. The mean age of the included patients ranged from 45 to 66 years (reported in 42 series (54 %)); the median age ranged from 42 to 73 years (reported in 30 series (38 %)). Mean APACHE II scores ranged from 13 to 28 (reported in 24 series (31 %)), while median APACHE II scores ranged from 12 to 30 points (provided in nine series (12 %)). Two studies reported APACHE III scores with a mean of 72 and 85, respectively, and one study reported a median APACHE IV score of 72. Only 10 series (13 %) provided information on the mean or median Mannheim Peritonitis Index (MPI) of the included patients. Mean MPI ranged from 24 to 34 points, median MPI ranged from 15 to 28. For only 9 series (12 %), the number of patients with bowel anastomoses was reported; it varied from 0 to 81 % patients (Online Appendix 2).

Indications for the OA

Information about the indications for leaving the abdomen open was provided in 59 of 78 series (76 %) (Table 2). In 31 series these indications were multiple, whereas in 28 series only one general indication was described. The most frequent single indication for open abdominal management was a planned relaparotomy strategy (15 series) [17, 21, 23, 25, 28, 32, 33, 43–50]. In one series patients undergoing decompression for ACS were selectively described, and four series included patients managed according to the principles of damage control surgery [34, 35, 51–53]. Five series reported on open abdominal management for drainage of intra-abdominal sepsis; considering the "abdominal cavity as if it were an abscess cavity" [22, 26, 27, 30, 54]. One study, describing two series of patients, applied TAC in patients with "a high risk of developing IAH/ACS", and one series included five patients with peritonitis and bowel edema preventing primary closure [13, 29]. For nineteen

series of patients, no information regarding the indications for open abdominal management could be derived.

Temporary abdominal closure techniques

In 68 of the 78 series only one type of TAC was evaluated. The remaining 10 series consisted of patients treated with various abdominal closure techniques. NPWT was described in 32 series (41 %) of OA patients [1, 5, 10, 12, 16, 17, 19, 20, 24, 25, 28, 29, 37–39, 41, 42, 53, 55–68]. Six series (8 %) described NWPT in combination with fascial traction (mesh or sutures) [30, 34, 35, 69–71]. In eight series (10 %) non-absorbable and/or absorbable meshes were used [14, 21–23, 48, 51, 72, 73]. The Bogota bag was applied in six series (8 %) [13, 14, 31, 46, 49, 74]. Zippers were applied in five series (6 %) [32, 33, 44, 50, 75]. Five series (6 %) included patients treated with dynamic retention sutures [36, 40, 52, 76, 77]. Two series (3 %) described loose packing [26, 54]. The Wittmann patch was used in one series (1 %) [78]. Three series (4 %) applied different TAC techniques that did not fall into one of the categories [13, 43, 47].

Delayed Primary Fascial Closure

The delayed fascial closure rate was reported in 63 of the 78 included series and ranged from 3.2 to 100 % with an overall weighted closure rate of 50.2 % (95 % CI 43.4–57.0, χ^2 $p < 0.001$, $I^2 = 90$ %). The weighted rates per TAC technique are given in Table 3. The highest weighted fascial closure rate was seen for NPWT *with* fascial traction (73.1 %, 95 % CI 63.3–81.0 %, χ^2 $p = 0.008$, $I^2 = 68$ %) and dynamic retention sutures (73.6 %, 95 % CI 51.1–88.1 %, χ^2 $p = 0.041$, $I^2 = 60$ %). TAC using a mesh or zipper showed the lowest delayed closure rates (34.2 %, 95 % CI 9.7–71.5 %, χ^2 $p < 0.001$, $I^2 = 95$ and 34.0 %, 95 % CI 16.7–56.9 %, χ^2 $p = 0.034$, $I^2 = 70$ %, respectively). In nine studies, it was not clearly described if any attempts to achieve delayed fascial closure were made [14, 22, 24, 32, 44, 45, 54, 73, 79].

Enteroatmospheric fistula

Seventy-three series reported the rate of enteroatmospheric fistula and ranged from 0 to 54.8 %. The weighted fistula rate for all included studies was 12.1 % (95 % CI 10.1–14.4 %, χ^2 $p < 0.001$, $I^2 = 67$ %). The highest rate was seen after mesh placement (17.2 %, 95 % CI 9.3–29.5 %, χ^2 $p = 0.012$, $I^2 = 66$ %), while NPWT with fascial traction showed the lowest weighted fistula rate (5.7 %, 95 % CI 2.2–14.1 %, χ^2 $p = <0.001$, $I^2 = 79$ %). NPWT (without fascial traction) had a weighted fistula rate of 14.6 % (95 % CI 12.1–17.6 %, χ^2 $p = <0.001$, $I^2 = 54$ %).

Mortality

Mortality rate was reported in 76 of 78 series and ranged from 0 to 60.8 %. Several studies excluded patients who died within the first days of open abdominal management, or those who died before a first attempt to achieve fascial closure was made (Online Appendix 2). The overall weighted mortality rate was 30.0 % (95 % CI 27.1–33.0 %, χ^2 $p < 0.001$, $I^2 = 69$ %). The lowest weighted mortality was seen in series describing dynamic retention sutures 11.1 % (95 % CI 4.5–25.0 %, χ^2 $p = 0.269$, $I^2 = 23$ %), while the highest mortality was reported after loose packing (40.0 %, 95 % CI 25.5–56.5 %, χ^2 $p = 0.085$, $I^2 = 59$ %) (Table 3).

Prospective studies

Twenty-two series of the included 78 (28 %) were (part of) prospective studies. TAC using NPWT was described in ten series, four series described NPWT combined with fascial traction. The remaining eight prospective series described the use of mesh [2], bogota bag [1], Wittmann patch [1], zipper [1], and various TAC techniques [3].

The prospective series on mere NPWT (608 patients) showed a weighted fascial closure rate of 53.9 % (95 % CI 42.2–65.3, χ^2 $p = <0.001$, $I^2 = 77$ %) and a fistula rate of 9.8 % (95 % CI 6.5–14.5, χ^2 $p = 0.228$, $I^2 = 23$ %). The four prospective series on NPWT with fascial traction (411 patients) showed a weighted fascial closure rate of 77.8 % (95 % CI 70.4–83.9, χ^2 $p = 0.109$, $I^2 = 51$ %) and a fistula rate of 4.3 % (95 % CI 2.4–7.7, χ^2 $p = 0.261$, $I^2 = 25$ %). These prospective data per closure type are in line with the overall results when the retrospective studies are included as well.

Discussion

This systematic review provides a comprehensive overview of current literature on the OA and TAC techniques in non-trauma patients with peritonitis. A total of 74 studies describing 78 patient series of 4,358 patients with an OA, of which 3,461 (79 %) had peritonitis, were included and analyzed. Overall, most included articles were of low methodological quality and a high heterogeneity existed among included studies. The indications for open abdominal management differed considerably and were not always clearly described. The most frequent described TAC technique was NPWT (32 series). A modification of NPWT, combining negative pressure with suture- or mesh-mediated fascial traction, was described in another 6 series and showed the highest weighted delayed fascial closure rate. Furthermore, a relatively low rate of enteroatmospheric fistula of

5.7 % was reported using this technique, whereas the overall weighted rate of fistula development in all series was 12.1 %. The mortality rate for all included patients was 30.0 %, reflecting the severity of the underlying conditions in patients with peritonitis and an OA.

Several challenging clinical situations can result in an OA. It can be a deliberate decision to leave the abdominal cavity open as part of damage control surgery, consisting of an initial operation aimed at obtaining surgical control followed by TAC and a postponed definitive treatment. Furthermore, the abdomen is usually left open after a decompressive laparotomy for ACS. An OA can also be the inescapable consequence of severe visceral edema preventing primary fascial closure at initial emergency surgery. Different underlying conditions can lead to one of the aforementioned scenarios. Trauma is the most frequent described etiology of the OA [3]. Damage control surgery is an accepted treatment strategy in trauma and ACS was long considered to be a disease of the traumatically injured patients only. In the non-trauma setting, damage control surgery is not an accepted standard treatment [80]. Although it is applied for severe secondary peritonitis in some centers, a laparotomy on-demand strategy, as opposed to planned relaparotomies (facilitated by TAC), has been demonstrated to result in better outcome and is the preferred treatment strategy over planned relaparotomy [81]. Therefore, the OA in patients with peritonitis should be predominantly the result of the inability to close; an inevitable situation. Besides the different indications for open abdominal management in trauma patients and patients with peritonitis, several other aspects warrant the evaluation of OA outcome for each etiology separately. The possibility of achieving one of the most important outcomes, delayed primary fascial closure, is mostly affected by the underlying etiology. Success rates are lower in non-trauma patients compared to trauma patients, and several studies identified peritonitis as an independent predictor of failure of fascial closure [1–3]. The risk of formation of an enteroatmospheric fistula also differs between trauma patients and patients with peritonitis. The infected abdomen is more fistula-prone. The inflamed and edematous bowel of peritonitis patients, often including enterostomies, is thought to be more susceptible of fistula formation, in particular in an open abdominal cavity [4]. High rates of enteric fistula have been described in patients with peritonitis [2]. Although previous systematic reviews have analyzed the OA and TAC for, amongst others, peritonitis patients separately, several studies since then have been published [2, 3]. Furthermore, this review is the first to only include series consisting of (predominantly) patients with peritonitis, and to report and analyze the described indications for open abdominal management.

The applied strategies leading to an OA in the included articles differed considerably. Most of the studies included patients with different indications or did not clearly report specific details. Of the articles describing one single indication, the majority applied an OA as part of a planned relaparotomy strategy. Most of these studies were published before 2000, and the superiority results of a laparotomy on-demand strategy were published in 2007. The indication for open abdominal management is closely related to the possibility of achieving delayed primary fascial closure. Successful fascial closure at the first re-exploration is more likely than during the second or third take back [15]. Furthermore, fewer re-explorations and a shorter duration of open abdominal management are associated with higher fascial closure rates [41, 70, 82]. Strategies requiring (usually) only one reoperation, such as planned open abdominal management followed by a second look for intestinal ischemia, therefore offer a higher change of fascial closure. Moreover, a prophylactic OA for intra-abdominal hypertension or for decompression of established ACS is associated with higher fascial closure rates [11]. Although this review only included patients with peritonitis, the diversity of the indications in the described articles still represents a considerable patient and treatment selection bias and may have had a profound effect on delayed fascial closure rates.

The overall weighted rate of delayed fascial closure in this systematic review was 50.2 % (95 % CI 43.4–57.0 %) but ranged from 34.0 to 73.6 % per TAC technique. The highest weighted fascial closure rate was reported in series describing NPWT with continuous suture- or mesh-mediated fascial traction. Combining NPWT with moderate tension on the fascia is believed to work in a synergistic way [83]. In a small prospective trial, Pliakos et al. compared vacuum-assisted closure with and without fascial retention sutures and found a significant increase of fascial closure when combining negative pressure with fascial traction [84]. Rasilainen et al. also found a higher closure rate after NPWT with mesh-mediated traction compared to a control group, but the underlying etiologies differed between groups. The intervention group of Rasilainen et al. was excluded from this review because it was not clear that it consisted for more than 50 % of patients with peritonitis [11]. In total, there were six studies describing NPWT with continuous fascial traction fulfilling the inclusion criteria. In two of these studies the OA was applied as part of damage control surgery, where the abdomen was left open deliberately as part of the strategy, even if closure was technically possible. This may at least in part explain the high success rate of fascial closure for NPWT with fascial traction.

The weighted pooled rate of enteroatmospheric fistula formation, one of the most feared complications of the OA, was 12.1 % (95 % CI 10.1–14.4). High rates of enteric fistula have previously been described in patients with

peritonitis [2]. Especially abdominal closure using negative pressure is suspected to be associated with fistulisation [4–6]. In the present systematic review, in series applying NPWT *without* fascial traction, a weighted fistula rate of 14.6 % was seen. But when NPWT was combined with continuous suture- or mesh-mediated fascial traction fistula risk dropped to 5.7 %. Although the included series in this review were categorized according to the type of applied TAC technique, these techniques were not standardized and a large amount of practice variations is likely to exist. For instance, differences in covering bowel with protective sheets or omentum might have contributed to the conflicting findings. This review could therefore not confirm nor reject the existing assumption that NPWT in the OA increases the risk of fistula formation.

The overall weighted mortality rate was 30.0 % (95 % CI 27.1–33.0 %). This finding is in line with previous reviews and reflects the severity of the underlying conditions in patients with an OA. A comparable mortality has been described for secondary peritonitis patients, regardless of open abdominal management [81]. The lowest mortality rates were described in series reporting high fascial closure rates, but we believe this mostly reflects differences in patient population (patient selection) and to a lesser extent a direct effect of the applied TAC technique.

Several limitations of this systematic review need to be addressed. First and most importantly, this review is limited by the poor overall quality and a substantial heterogeneity of the included studies. The majority of the included articles describe retrospective observational studies. Only a few comparative studies were included and only one randomized trial, of which one treatment arm fulfilled the inclusion criteria. Secondly, only a minority of the included articles described the indications for the open abdominal management, representing a considerable patient and treatment selection bias. Besides the applied indication and chosen TAC technique, several other aspects influence outcome in patients with an OA. Management of severe sepsis and septic shock is complex and consists of multiple elements, such as resuscitation, respiratory support, and infection control [85]. Furthermore, essential to successful management of an OA is a dedicated medical team. Every attempt should be made to realize early abdominal closure; a longer duration of TAC makes successful delayed closure less likely [70, 86]. A large variability in the aforementioned aspects of patient management likely exists and has potentially influenced outcomes and hinders comparing studies and patients. Furthermore, the overall lack of good quality evidence did not allow for a definite conclusion which type of TAC works best for non-trauma patients with peritonitis.

In conclusion, this systematic review on the OA in non-trauma patients with peritonitis describes the indications and the applied TAC techniques in a large number of patients. The published results for NPWT with continuous fascial traction were superior to those of mere NPWT and other techniques, in terms of achieving delayed fascial closure and risk of enteroatmospheric fistula. However, there was an overall lack of good quality evidence and a substantial heterogeneity existed between the included studies.

Although a randomized trial may be hard to conduct in this complex condition, this review highlights the need for prospective studies with clear descriptions of included patients, applied indications for open abdominal management, and outcome evaluation. Important variables such as presence of a colostomy while applying TAC, presence of new bowel anastomoses, and extent of peritonitis and contamination need to be prospectively recorded in a standardized way. Endpoint assessment needs to be assessor blinded, and success rates of closure need to be verified with computed tomography imaging. This will in future allow for more firm conclusions on the appropriate indications and preferred TAC techniques in patients with peritonitis.

Conflict of interest None.

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