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ORIGINAL ARTICLE

Delayed Closure of 61 Open Abdomen Patients Based on an Algorithm

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Abstract Hemodynamic resuscitation, source control, and delayed abdominal closure are the three fundamental steps for open abdomen (OA) management. When to start delayed abdominal closure and how to determine which delayed closure method should be applied to each OA patient are not clarified in the literature. We evaluated an algorithm that was developed to address these two questions. A retrospective chart review was conducted for OA patients treated for according to the algorithm. When hemodynamic stabilization and source control using negative pressure therapy resulted in regression of sepsis and decreased procalcitonin levels, patients were assigned to either the skin-only or fascial closure groups according to their Björck scores and open abdominal fascial closure (OAFC) scores. The novel OAFC scoring system was created by adding age and malignancy to the sequential organ failure assessment (SOFA) score. For skin-only closure, skin flaps and skin grafts were used; for fascial closure, an abdominal re-approximation anchor system (ABRA) or ABRA plus biologic mesh was applied. From January 2008 through September 2014, 108 OA patients were managed based on the algorithm; 61 were included in this study. Abdominal closure rate was 90.2 % (55/61). Overall hospital mortality rate was 11.4 % (7/61). Small hernias developed in only 12.5 % (4/32) of the fascial closure group. In this retrospective study, the algorithm with the novel OAFC score provided practical and valid guidance to clarify when to start delayed abdominal closure and which delayed closure method to use for each OA patient.

Keywords Open abdomen · Delayed abdominal closure · SOFA score · Björck score · VAC therapy · ABRA

Introduction

Open abdomen (OA) management is a life-saving and compelling strategy for use in damage-control surgery and in the management of abdominal compartment syndrome (ACS), ruptured aortic aneurysms, and severe generalized peritonitis [1, 2]. The patient is at high risk of developing major complications during the OA period. Multiple organ failure (30–40 %), intra-abdominal abscess (83 %), and devastating entero-atmospheric fistula (EAF) (5 to 25 %) have been reported to occur in OA patients [3–5]. Mortality rates up to 50 % have been reported [2, 6]. The risk of mortality is even higher in the infected OA [2, 3, 7].

The three fundamental steps for successful management of the OA patient are hemodynamic resuscitation, adequate source control of abdominal sepsis, and delayed abdominal closure. The risk of developing complications increases when the duration of the OA is prolonged [8, 9]. The mortality rate of a septic OA with an EAF was as high as 70 % in the past decades but currently is lowered to 42 % by means of advanced modern intensive care unit (ICU) and improved surgical techniques and equipment [9, 10]. Lower fistula rates were reported after management of OA with negative pressure therapy (NPT), which has a visceral protective layer [11].

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After hemodynamic stabilization and source control in the OA, there are currently many delayed abdominal closure techniques in conjunction with NPT to be considered including closure using a skin flap, skin graft, and a mesh or dynamic wound closure system [6, 12]. Each of these delayed closure systems focus on either skin closure or fascial closure and have specific advantages and disadvantages. Fascial closure is the gold standard for all OA patients but requires more operations and longer management. On the other hand, the skin closure method results in fewer operations and shorter duration of OA management but heals with a debilitating giant hernia. There is no consensus in the literature about when to start delayed abdominal closure and which closure strategy should be applied to which OA patient.

In this retrospective study, we evaluated the results of using an algorithm to determine when to start delayed abdominal closure and which type of closure to use based on patient characteristics. The algorithm was based on the Björck OA score and the open abdominal fascial closure (OAFC) score, a novel scoring system that combines age, malignancy, and the sequential organ failure assessment (SOFA) score.

Patients and Methods

A retrospective chart review was conducted according to institutional guidelines for use of deidentified patient information. OA patients treated with the same algorithm were excluded if the duration of OA management was less than 7 days or patient data were not accessible. The patient data collected for the study included demographics, body mass index (BMI), acute physiology and chronic health evaluation (APACHE) II score [13], SOFA score [14], and Manheim peritonitis index (MPI) score [15]. Björck scores for all patients were modified according to the new scoring system defined in 2013 by the World Society of the Abdominal Comportment Syndrome [16, 17]. Other data collected included procalcitonin level, diameter of the OA at the first NPT application, duration of the first NPT and abdominal re-approximation anchor system (ABRA) applications after the first laparotomy, as well as lengths of intensive care unit (ICU) and hospital stay. The rates for overall hospital mortality, abdominal closure, and hernia development were also emphasized in detail.

General supportive approaches for hemodynamic stability, including mechanical ventilation, correction of electrolyte and acid/base imbalances, as well as hypothermia, and application of vaso-active drugs, were performed. Broad spectrum antibiotics were tailored to all patients and adjusted according to the clinical situation and procalcitonin level. Along with hemodynamic stabilization, patients underwent operations for source control as early as possible. After debridement and irrigation with warm saline, NPT was applied to all OA patients under general anesthesia. If there was an EAF within an OA, different types of EAF control strategies based on fistula type were used in conjunction with the standard abdominal NPT dressing [18, 19]. Delayed abdominal closure was considered after hemodynamic stabilization of the patient, source control of the OA, regression of sepsis, and decrease in procalcitonin level to <1.0 ng/dl [20].

We developed the open abdomen fascial closure (OAFC) score, a novel system to help discriminate OA patients whose fascia should be closed. The OAFC score added age and malignancy as important parameters to the SOFA [21, 22] score (Table 1). The SOFA score was obtained just before starting to close the OA, while age and malignancy were scored separately. Closure technique was determined according to Björck and OAFC scores. If an OA patient had a Björck score of <3, the patient was classified according to the OAFC score.

Skin-Only Closure Group

If the Björck score <3 and the OAFC score was >3, delayed abdominal closure was done with only a skin flap or a skin graft, in order to simplify OA management by decreasing the number and duration of operations. For delayed closure with a skin flap, the skin flap was dissected from the fascia and only skin was closed without fascial closure if the skin edges could be approximated without any difficulty (Fig. 1a).

In a frozen abdomen (Björck score ≥3), fascia and skin could not be dissected from visceral tissue, so closure could not be done with a skin flap. After development of granulation tissue, a frozen OA was closed with a skin graft (Fig. 1b).

Fascial Closure Group

For OA patients with a Björck score <3 and an OAFC score ≤3, fascial and skin closure were achieved using NPT and an abdominal re-approximation anchor system (ABRA; ABRA® Abdominal Wall Closure System, Canica Design, Inc., Almonte, Ontario, Canada, marketed by Southmedic Inc., Barrie, Ontario, Canada) (Fig. 2a). If there was a fascial defect after application of NPT and ABRA, biological mesh was implanted to repair the defect (Fig. 2b).

All OA patients were treated with NPT (the V.A.C.® Abdominal Dressing System and ABThera™ Open Abdomen Negative Pressure Therapy System, KCI, an Acelity company, San Antonio, TX, USA). After debridement and irrigation of the OA with warm saline, a perforated silicone sheet was placed over the bowel under the fascia. A foam dressing was placed over the silicone sheet, and an interface pad with attached suction tubing was applied. Negative pressure was adjusted between −50 and −125 mmHg continuously or intermittently (4 or 7 min of high negative pressure was followed by 1 or 2 min of low negative pressure, respectively). The dressing was changed every 2–5 days [23].

Table 1 Open abdomen fascial closure (OAFC) score

SOFA score	
Age score	
<65	0
65–75	1
>75	2
Malignancy score	
No malignancy	0
R0 resection	1
R1 resection	2
R2–R3 resection	3
Total	

ABRA was applied as early as possible. A series of midline crossing elastomers were inserted through the full thickness of the abdominal wall at a distance of approximately 5 cm from the medial fascial margin. The elastomers are aligned about 3–5 cm apart across the defect and fixed to button anchors on both sides of the OA. The optimal tension was obtained by stretching the elastomers 1.5–2 times their tension-free length. When all the wound edges reapproximated completely, the fascia were sutured one by one with PDS 1–0 (Ethicon, a Johnson & Johnson company, Somerville, NJ, USA). Skin closure was performed 1–3 days after fascial closure, if there was no sign of infection at the wound site. Approximately 1 week after fascial closure, the ABRA anchors were removed one by one [23].

If a large fascial defect remained after approximation of skin edges with ABRA, biologic mesh implantation was used for restoration. The edges of the fascial defect were prepared, and porcine acellular dermal matrix (Permacol™ Surgical Implant, Covidien, Mansfield, MA, USA) was implanted in the fascial defect by suturing it to the fascial edges with PDS 1–0.

The patients were intubated at the first laparotomy and first application of NPT and ABRA. After source control had been achieved, NPT dressing changes and ABRA re-approximations were performed either under general anesthesia with laryngeal mask airway to avoid using neuromuscular blockade or under sedation mainly with analgesic control. All patients received non-opioid analgesics routinely for pain treatment. As rescue analgesics, tramadol and/or morphine were administered.

After hemodynamic stabilization, if enteral nutrition (EN) was not feasible, total parenteral nutrition (TPN) was started in all patients. EN was initiated as early as possible and increased step by step after intestinal continuity had been established. Caloric and protein requirements were arranged as follows: 30–35 kcal/kg/day and 1.5–2 g/kg/day, respectively; vitamins and trace elements were also replaced.

The parameters were given as rate and mean and standard deviation in this study.

Results

Between January 2008 and September 2014, 108 OA patients with different etiologies were managed by the same surgical team using the same algorithm (Fig. 3). Of these OA patients, 61 met the inclusion criteria; 24/61 OA patients were female and 37/61 were male. Mean age of patients was 64.8±16.5 and mean BMI was 28.4±7.3.

APACHE II, SOFA, and MPI scores; procalcitonin level; and diameter of OA are shown in Table 2. Expected mortality according to SOFA was more than 40 %. Twenty (32.7 %) of 61 OA patients had malignancies, and 44/61 (72 %) patients had intra-abdominal sepsis. The distribution of patients according to their Björck scores [Björck 2014] was summarized

a b

Fig. 1 **a** Closure with only skin flap approximation: (*a*) OA (diameter 23×19 cm) with EAF 18 days after the first laparatomy; (*b*) source and EAF control by NPT; (*c*) skin was dissected from fascia and closed step by step; (*d*) OA was closed by skin flap approximation. **b** Closure with skin graft: (*a*) OA (diameter 45×50 cm) with EAF 8 days after the first laparotomy; (*b*) source and EAF control was done with Tube VAC; (*c*) EAF was converted to ileostomy by the help of NPT; (*d*) after granulation tissue occurred, OA was closed with skin graft

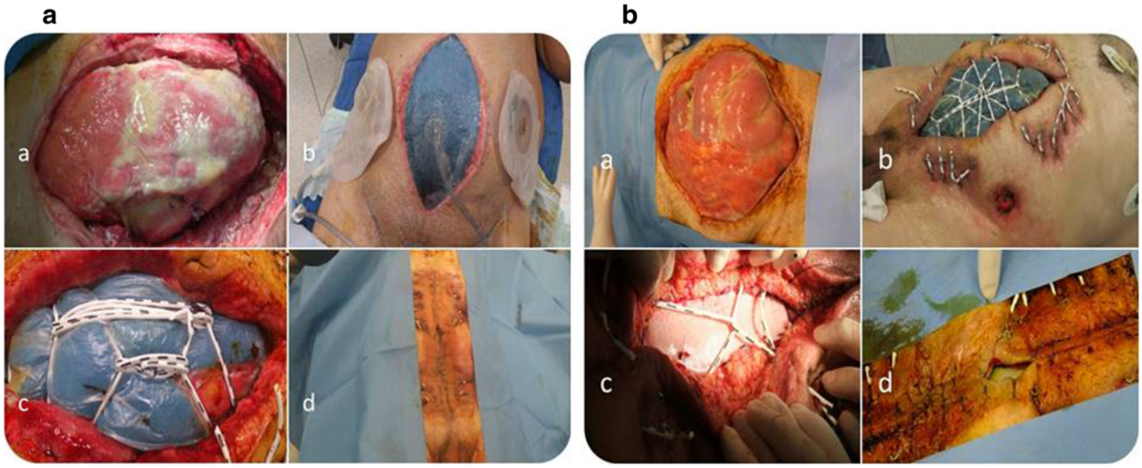

Fig. 2 **a** Closure with ABRA: (*a*) OA (diameter 21×18 cm) with EAF 16 days after the first laparotomy; (*b*) EAF control was done by opening proximal ostomy and closing the fistula; (*c*) ABRA was added; (*d*) Fascia and skin of OA was closed. **b** Closure with ABRA+biologic mesh; (*a*) OA (diameter 26×24 cm) with EAF from ureteroileostomy and ileus; (*b*) fistula control was achieved with intra-conduit NPT and ABRA was added; (*c*) biologic mesh was implanted to repair fascial defect after ABRA application; (*d*) OA was closed

in Table 2 at the first NPT application; 27/61 (44.2 %) OA patients had an EAF, and 25/27 patients with an EAF were admitted to our clinic from other hospitals. First NPT and ABRA application time, length of ICU and hospital stay are also given in Table 2.

Delayed closure of the OA was achieved in 55 of 61 (90.2 %) patients. In the skin-only closure group, 12 OA patients (Björck score <3 and OAFC score >3) were closed with skin flap. Skin grafting was used for delayed closure in 11 OA patients: 8 patients with frozen OA (Björck score ≥3) and 3 patients (Björck score <3 and OAFC score >3) whose OA could not be closed with a skin flap. In the fascial closure group, 32 OA patients (Björck score <3 and OAFC score ≤3) achieved delayed closure: 29 with ABRA and 3 OA with

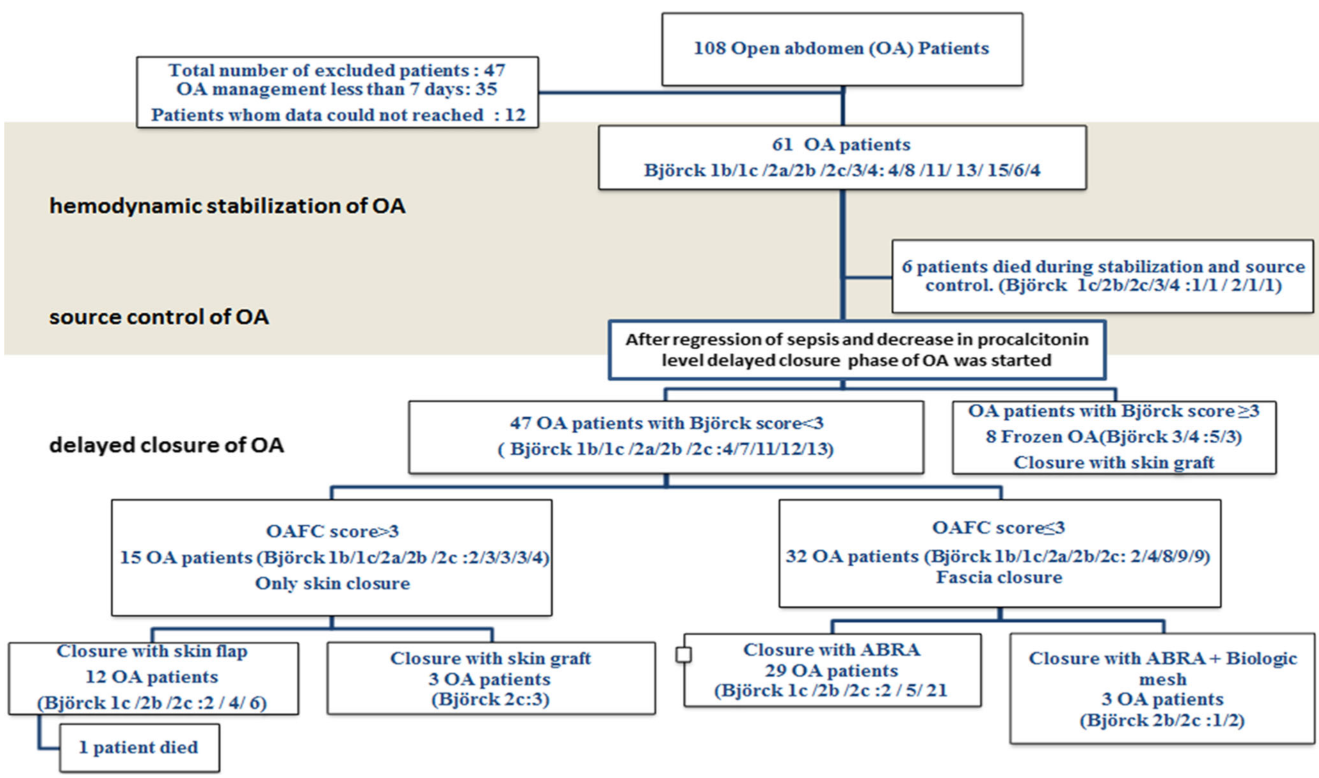

Fig. 3 The treatment algorithm incorporated the novel open abdomen fascial closure (*OAFC*) score that was used in conjunction with the Björck score to determine when to initiate delayed closure of the OA and which patients should receive fascial versus skin-only closure. The flow of patients through the algorithm is presented according to their OAFC and Björck scores. *OA* open abdomen, *OAFC* open abdomen fascial closure, *ABRA* abdominal re-approximation anchor system

Table 2 APACHE II, SOFA, MPI, and Björck scores; procalcitonin level; diameter of OA; first NPT and ABRA application time; and length of ICU and hospital stay

APACHE II	21.3±5.3
SOFA score	11.0±4.1
MPI score	35.2±5.3
Björck score (patient number in that score)	1b (4), 1c (8), 2a (11), 2b (13), 2c (15), 3 (6), 4 (4)
Procalcitonin level (ng/ml)	5.3±4.8
Width of OA defect (cm)	18.5±6.4
Length of OA Defect (cm)	25.0±6.9
Application of ABRA after first laparotomy	16.2±3.5
Application of 1st NPT after first laparotomy	11.4±7.3
Length of hospital stay (days)	38.8±21.0
Length of ICU stay (days)	12.2±9.1

APACHE II acute physiology and chronic health evaluation II, *SOFA* sequential organ failure assessment, *MPI* Manheim peritonitis index, *ICU* intensive care unit, *NPT* negative pressure therapy, *ABRA* abdominal re-approximation anchor system

ABRA and biologic mesh. Of the 32 patients in the fascial closure group, only 4 (12.5 %) developed hernias with diameters of 3×4, 2×3, 6×5, and 3×3 cm, respectively. OA patients in the fascial closure group also had an average of 3.2 more operations per person than OA patients in the skin-only closure group.

Mean follow up-time for OA patients was 19.1±14.6 months. In this study, abdominal closure rate was 90.2 % (55/61), 54/61 (89 %) patients were discharged from the hospital uneventfully. During the hemodynamic stabilization and source control phases, 6/61 (10 %) patients died, and during the delayed closure period, 1/61 (2 %) patient died. The overall hospital mortality rate was 11.4 % (7/61).

Discussion

There are two main points during the delayed closure phase of OA management that are not clarified in the literature: when to initiate delayed closure and whether or not the fascia should be closed. We defined an algorithm to clarify these two obscure points for the first time in the literature. After hemodynamic stabilization and source control, we determined starting time for delayed closure based on regression of sepsis and decrease in the procalcitonin level [7, 24].

Considering both the Björck score and the OAFC score clarified the most suitable delayed closure method for each OA patient in our algorithm. In this very complex group of OA patients, the OAFC score was a novel and an easy-to-use tool that was helpful in identifying those who would most likely be harmed by further operations and anesthesia. Accepting the development of planned ventral hernias for patients in the skin-only closure group avoided further increase in patient morbidity and mortality and in cost by reducing the number of operations and duration of OA management for these highly compromised patients. On the other hand, the use of ABRA (our preference) or mesh-mediated approximation on patients in the fascial closure group was intended to prevent the development of large debilitating hernias.

The development of late ventral hernias remains as a major concern after OA management. The reported rates of hernia development after delayed primary closure of infected OA have ranged from 25 to 67 % [5]. In our study, apart from the 23 patients in the skin-only closure group with planned ventral hernia, small hernias developed in only 4 (12.5 %) of the 32 patients in the fascial closure group.

Delayed primary closure rates in septic OAs have been reported between 33 and 88 % in previous studies [5, 24]. In our study, the abdominal closure and overall mortality rates were 90.2 and 11.4 %, respectively. This success may be due to our algorithm for delayed closure, decreased the number, and duration of operations in patients with OAFC score >3.

In our study, NPT was used for all patients as a part of the source control strategy. Kubiak et al. demonstrated in non-clinical porcine intra-abdominal sepsis model of multiple organ injury that application of peritoneal NPT significantly reduced lung, kidney, liver, and intestinal pathology and improved pulmonary parameters by the mechanism of peritoneal cytokine removal [25].

In a systematic review about delayed abdominal closure, Quyn et al. reported that fascial closure rates for the Wittmann™ patch (Starsurgical, Burlington, WI), abdominal dynamic retention sutures, and NPT were 78, 71, and 61 %, respectively. It was emphasized that temporary abdominal closure has developed from simple packing into NPT-type systems. The Wittmann™ patch and NPT were reported to have the best outcome in the absence of sepsis; however, in the septic OA, NPT system had the highest delayed closure rate and the lowest mortality rate [26].

In a retrospective study Connolly et al. reported that refistulation occured more frequently when the abdominal wall reconstruction was accomplished with prosthetic mesh (7/29, 24.1 %) than with sutures (0 of 34, 0 %). An especially high rate of refistulation (5/12, 41.7 %) was associated with use of porcine collagen mesh [27]. In our study, refistulation did not develop in any patients, even in the three patients whose delayed closure included use of porcine mesh. This may be due to the fact that the porcine mesh was implanted into the fascial defect in the final stage of the OA management and had little contact with the visceral tissue.

In a multicenter prospective study of 111 OA patients who were treated with NPT and mesh-mediated fascial traction, Acosta et al. reported a fascial closure rate of 80 % and intestinal fistula developed in eight patients [28]. In our study group, the fascial closure rate was 90.2 % and no new intestinal fistula developed. We speculate that using the NPT visceral protection layer correctly and ABRA instead of mesh-mediated closure may have decreased new intestinal fistula development.

Acosta also stated that if mesh is used for management of infected OA, source control will be more difficult and EAF may develop [28]. Use of mesh-mediated fascial traction methods may be more suitable in non-infected and OA patients with low-grade Björck score, whereas ABRA can be used in the severely infected OA patients with high-grade Björck score in conjunction with NPT [5, 12]. In our study, ABRA was used in 32 OA patients. Pressure sores on skin may develop by transmural traction on the buttons or anchor during ABRA application [5, 12]. In our cases, superficial pressure sores also developed and eventually healed well. Although the OA is managed step by step in a sequential manner, the challenging and compelling nature of these patients may require that the steps of our algorithm inevitably overlap each other in some cases. Especially when source control cannot be optimally achieved, ABRA may be a more suitable option compared to mesh.

One of the limitations of our study is that our OA patients were not a homogenous group and the other is that this study was not a prospective randomized study.

Conclusion

Based on our results, using this algorithm with the novel OAFC score may assist in determining when to start delayed abdominal closure and which type of closure technique to use on each OA patient. This guidance may increase the success rate of delayed closure of OA patients without increasing morbidity and mortality.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

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