Vertical Mesh-Mediated Fascial Traction and Negative Pressure Wound Therapy: A Case Series of Nine Patients in General and Vascular Surgery

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ABSTRACT

Open abdomen (OA) is a well-established procedure for life-threatening illnesses such as septic peritonitis, abdominal compartment syndrome (ACS), and damage control surgery (DCS). Furthermore, in cases of life-saving aortic repair after perforation of abdominal aortic aneurysm, an OA is sometimes indicated. Definitive fascial closure (DFC) is one of the main goals during treatment to prevent further complications such as fistula formation and the development of an incisional hernia. In 2019, a new technique was introduced for OA using a device called fasciotens®Abdomen to apply dynamic traction to the abdominal wall through vertical mesh-mediated fascial traction (VMMFT). We present a case series including nine patients and show an algorithm for OA combining VMMFT and negative pressure wound therapy (NPWT).

Methods: **Two patients in a vascular surgery unit and seven patients in an abdominal surgery unit with an OA were treated with VMMFT in combination with NPWT between September 2019 and June 2023.**

Results: **A DFC was achieved in seven of nine cases. The mean duration of OA was 9.6 ± 3.8 days, and fascial dehiscence at the beginning of OA was 14.2 ± 4.0 cm on average. Time to DFC after VMMFT was established was 6.2 ± 3.5 days (mean). No method-related complications occurred.**

Conclusion: **The standardized combination of VMMFT and NPWT gave positive results in achieving DFC in our heterogenic patient group. Following a strict treatment pathway as shown here seems to improve OA outcome. It represents a promising further development of mesh-mediated fascial traction for OA treatment.**

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INTRODUCTION

OA is a well-established procedure for life-threatening illnesses such as septic peritonitis, abdominal compartment syndrome (ACS), and damage control surgery (DCS).[1] Furthermore, in cases of perforated abdominal aortic aneurysms, where an open aortic repair is performed, an OA is frequently indicated.[1,2] This is especially true due to fluid resuscitation due to the acute blood loss and circulation shock leading to edema of the small and large bowel in a short time and hindering a DFC. OA for critically ill patients is often challenging, especially when the OA must be performed for several days or weeks. A prolonged OA is associated with a higher complication rate, including entero-atmospheric fistula and bowel adhesions.[1-3] The guidelines from the World Society of Emergency Surgery state that an abdominal closure should be attempted as soon as possible, otherwise, closure becomes unlikely.[4]

The techniques used to facilitate and achieve a DFC after OA have recently undergone drastic changes. OA now usually consists of a combination of dynamic fascial traction and NPWT instead of static techniques such as a Bogota Bag. For OA, the introduction of NPWT helps to achieve evacuation of the often large collections of fluid that form inside the abdominal cavity and the abdomen is kept covered.[5,6] To prevent fistula formation, it should be combined with a visceral protective layer (VPL).[7] For dynamic fascial traction, mesh-mediated fascial traction (MMFT) is nowadays the most common technique.[1,8] An alloplastic mesh is sutured between the fascial edges using moderate tension on the fascia. During every relook operation, the mesh is opened at the midline and, depending on the intraabdominal pressure (IAP) and the edema, it is sutured tighter at the midline. Average DFC rates of 83.5% can be achieved. Nevertheless, rates of incisional hernias between 21 – 54% have been reported.[9] One of the main disadvantages is an increase in IAP, if the mesh-mediated traction is applied too early in the course of the OA.[10] Therefore, it can only be applied at a later stage in treatment.[11] Nowadays, MMFT is normally combined with NPWT. This combination is called Vacuum-Assisted Wound Closure and Mesh-Mediated Fascial Traction (VAWCM).[9]

In 2019, a new technique for OA was introduced using a vertical traction device (VTD, fasciotens®Abdomen, Cologne, Germany) to apply VMMFT.[12] The feasibility of this method was shown in a retrospective study with 20 patients. In that study, vertical fascial traction was used in combination with either a Bogota Bag or NPWT. A DFC was achieved in all patients with a 0% mortality.[13] Nevertheless, a tailored approach and feasible algorithm for VMMFT are needed to change daily care to routine use. Furthermore, it is important to identify patient groups for whom VMMFT in combination with NPWT is suitable.

This case series consisting of 9 patients describes a standardized surgical approach to combine abdominal NPWT with VMMFT. With our experience, we developed an VMMFT algorithm adapted from the Koblenz algorithm for the treatment of OA.[14,15]

Table I
General patient characteristics

Gender, male/female	4/5
Median age (y)	62.0 (age range: 50-89)
Median BMI (kg/m²)	29.04
Arterial Hypertension	4/9
Cardiac disease	3/9
Hepatic disease	1/9
Renal disease	2/9
Malignant disease	2/9
Diabetes mellitus type II	3/9
Smoker	1/9
Mortality	3/9 (33%)

MATERIALS AND METHODS

Study population

This case series is a retrospective analysis of 9 patients with an OA between September 2019 and June 2023 at two different secondary care hospitals in Germany (Table I). In each hospital, the same surgeon performed device application and supervised treatment during a hospital stay. Two patients were treated in one hospital (Cologne) in a unit for vascular surgery. The other seven patients had an open abdomen due to a septic cause and were treated in another hospital (Brilon).

The data were collected in the EHS Open Abdomen Registry (ehs-openabdomen.com).[16]

Data management and statistical analysis

The EHS Open Abdomen Registry is a multinational and multicentric OA Registry to collect data on OA treatment including patient characteristics, Intensive Care Unit (ICU) parameters and outcome data.[16] The data were analyzed based on the authors' own registry records and thus the study is covered by the registry's ethics approval. Data were analyzed using Excel (Microsoft® Excel® für Microsoft 365 MSO Version 2312, Microsoft Corp., Redmond, WA, USA). Due to the small sample size, a test for a normal distribution was carried out using the Kolmogorov-Smirnov test and a quantile-quantile plot (data not shown).

SURGICAL TECHNIQUE

A median laparotomy was performed in all cases due to the underlying disease. If DFC could not be achieved because of visceral edema, septic condition, or planned relook operation, an OA was initiated. In some cases, patients were first treated using a VPL and abdominal NPWT (KCI, 3M, Saint Paul, MN, USA; Smith and Nephew, UK) with a negative pressure of 60-80 mmHg.

Table II
Detailed Case Description

	Admission diagnosis	Primary surgery	Indication for OA	Start OA during primary surgery	Sepsis during OA	Fascial dehiscence (begin of OA [cm])	Days of fascial traction	Days of OA	Complete fascial closure	ICU treatment (days)	Björck-Classification	Apache Score
Case 1	Adhesive ileus	Laparotomy with decompression and adhesiolysis	ACS	Yes	Yes	14	4	6	Yes	12	IIC	14
Case 2	Hollow organ perforation	Bowel resection with anastomosis	Peritonitis Hollow organ perforation	Yes	Yes	8	3	8	Yes	11	IC	8
Case 3	Planned reversal ileostomy	Ileostomy reversal surgery	Burst abdomen	No	Yes	12	9	16	No	33	IIC	16
Case 4	Ileus with parastomal hernia	Laparotomy with adhesiolysis	ACS, peritonitis	Yes	Yes	10	2	6	Yes	25	IIIB	28
Case 5	Perforated iliac aneurysm	Aorto-bifemoral Y-Prosthesis	ACS due to massive fluid transfusion	Yes	No	18	14	15	Yes	29	IA	22
Case 6	Perforated abdominal aortic aneurysm	Aorto-biiliac Y-Prostheses	ACS due to massive fluid transfusion	Yes	No	20	8	13	Yes	15	IA	20
Case 7	Adhesive ileus after bowel resection	Bowel resection with anastomosis + Decompression	Abdominal Compartment Syndrome	Yes	Yes	20	4	6	Yes	12	IIIa	8
Case 8	Mesenteric ischemia, hemicolectomy + small intestine, fascial necrosis, burst abdomen	Bowel resection with anastomosis	Burst abdomen	Yes	Yes	12	6	8	No*	8	IIa	18
Case 9	Hemicolectomy r. with carcinoma, fascial necrosis under cortisone, burst belly	Bowel resection with anastomosis	Burst abdomen	Yes	Yes	14	6	8	Yes	16	Ia	10
Mean± SD	-	-	-	8/9	7/9	14.2±4.0	6.2±3.5	9.6±3.8	7/9	17.8±8.4	-	16±6.4
Median	-	-	-	-	-	14	6	8	-	15	-	16
IQR	-	-	-	-	-	6	4	7	-	13	-	10

Time of VMMFT application differed between cases (Table II) and followed either the surgeon's assessment or the algorithm below. The following steps describe the combination of an abdominal NPWT and VMMFT

A doubled strip of a Vicryl® woven mesh (Ethicon, Johnson & Johnson, Cincinnati, OH, USA) (maximum width 2-3 cm) was sutured onto both fascial edges using a running suture (Fig. 1a).

6 U-sutures (polyfil, USP-2, Novosyn® BBraun, Melsungen, Germany; Vicryl® Ethicon, Johnson&Johnson) per side were stitched into the doubled vicryl mesh (Fig. 1b).

A VPL was inserted into the abdominal cavity as far as possible laterally (Fig. 1c). It serves as a protection between the abdominal wall and the intestines to prevent adhesions and fistula formation.

Foam was then positioned centrally between the two edges of the mesh (Fig . 1d). Two narrow foam strips were also placed between the subcutaneous fat and the fascia/mesh (Fig.1d). All traction sutures were placed laterally on both sides and the medial foam was fixed using a wide adhesive dressing strip (Fig. 2a).

Another adhesive dressing strip was placed halfway on the middle part of the vacuum foam and folded towards the middle (adhesive side facing up) (Fig. 2b,c). The traction sutures of one side were folded medially under tension onto the adhesive side (Fig. 3d). Another strip of adhesive dressing was now applied to the exposed adhesive film, as well as the traction sutures, and laterally to the skin (Fig. 3e,f).

The procedure was repeated for the other side (Fig. 3g). Finally, the trackpad was placed in the center of the adhesive dressing (Fig. 3h). A continuous negative pressure between 60-80 mmHg was

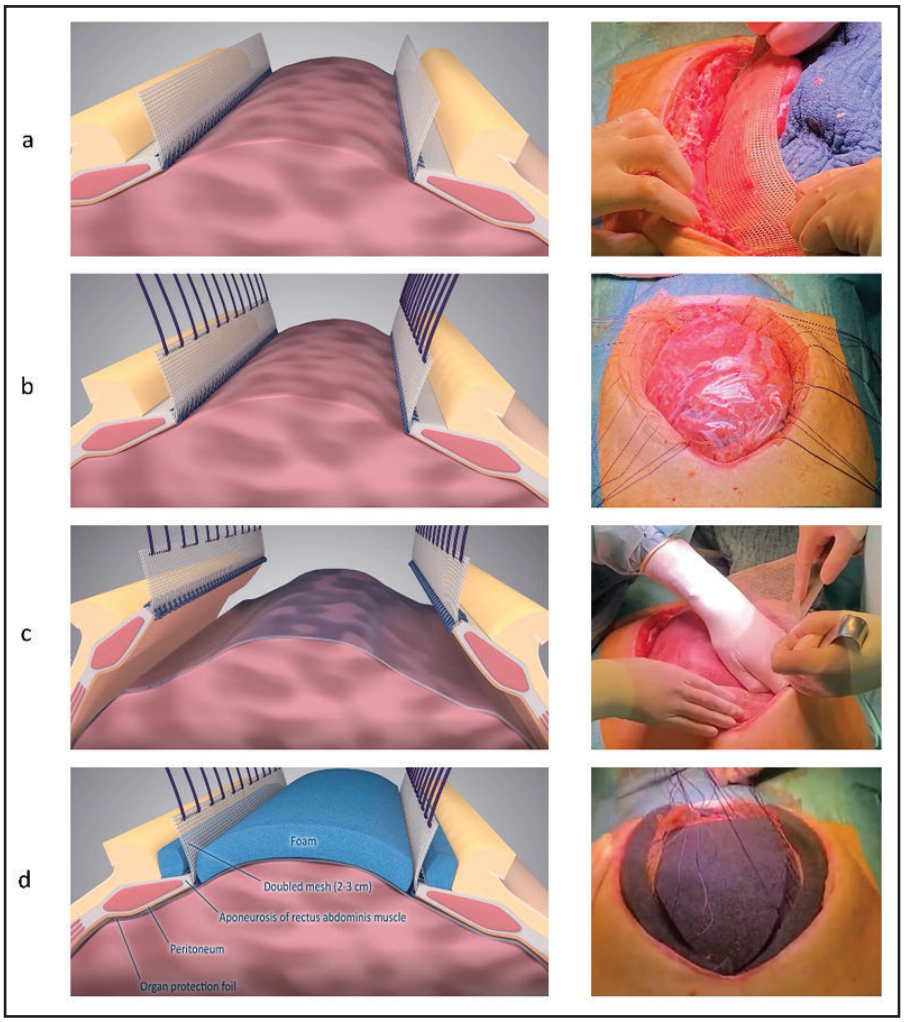

Figure 1. Preparation of traction sutures and NPWT (courtesy of Fasciotens GmbH and Department for General and Abdominal Surgery, Maria-Hilf Hospital, Brilon, Germany)
Left: Schematic illustration showing the preparation for NPWT in combination with volume-increasing fascial traction. Right: Corresponding intraoperative photograph.
a. - An approx. 4 cm-wide strip of a commercially available mesh is sutured to both sides of the fascia using a running suture. The mesh is doubled in terms of reinforcement.
b. - 6 sutures (USP 2) per side are stitched equally distributed to both meshes using U-sutures.
c. - The organs are covered by a commercially available VPL. It is important to reach the film as far laterally as possible.
d. - A foam (commercially available NPWT system) is placed between the mesh edges covering the abdominal cavity. Furthermore, 2 strips of foam are placed between the mesh and the subcutaneous tissue/skin on both sides.

applied (KCI, 3M, Saint Paul, MN, USA; Smith and Nephew, UK).

The device was placed on the patient and the traction sutures were clamped in a suture-retention frame. In the case series described above, traction forces between 60-80 N (6-8 according to the scale of the device) were applied during therapy in the ICU. The traction period was divided into approximately 5h traction, followed by 1h of traction breaks.

As soon as the fascial adaptation was possible without or with low tension, the doubled mesh was removed and the fascia was closed with a slowly absorbable running suture.

Concept of changing the direction of traction

Two directions of traction were used for treatment of this patient cohort. Vertically-directed traction was used to enlarge the abdominal cavity as much as possible, especially in the initial phase of OA with protruding organs because of edema. Using a similar approach called IFT (intraoperative fascial traction) for the treatment of large ventral hernias, we and other groups have noted that diagonally-directed traction (approx. 45°) facilitates myofascial advancement of the abdominal wall.[17-19] Since no standard criteria have been defined for deciding when a change from vertical to diagonal traction can be carried out, we used available patient parameters for decision-making. The parameters were IAP, edema, renal function, and ventilation (peak respiratory pressure). For each patient, an individual assessment was performed regarding the threshold of the parameters. Since the best results for myofascial advancement were achieved while the patient was under relaxation, we developed an approach called diagonally amplified vertical intermittent traction (DAVIT) with approx. 100N for 30 minutes which was carried out at regular intervals (e.g., 1x/1-2 days) to facilitate fascial closure at the end of treatment. During therapy in the ICU and in several surgical revisions due to primary disease, the patient's condition was evaluated periodically. Depending on the results, the direction of traction was modified.

Development of a VMMFT algorithm

After treating the patients and considering the results below, we adapted the Koblenz algorithm for OA treated with VAWCM[14,15] and made alterations to use it for VMMFT. The pathway is shown below (Fig. 4) including VMMFT using fasciotens®Abdomen in combination with a NPWT and a VPL.VMMFT was established during the first re-look surgery if the abdomen could not be closed due to intestinal edema, abdominal compartment syndrome or fascial necrosis.

RESULTS

Causes of non-septic OA included ACS after aortic aneurysm rupture and open repair. Septic OA resulted from ACS, peritonitis, and a burst abdomen. All cases were treated during OA with VMMFT. All patients were treated in the intensive care unit (ICU) and were sedated and ventilated until definitive fascial closure was achieved. The general patient characteristics are presented in Table I. Of the nine patients, 4 were male and 5 were female and the mean age was 62 years with an age range of 57 to 89 years. A small percentage of the patients had a medical history of diabetes mellitus, arterial hypertension, cardiac, renal, or hepatic disease. Furthermore, the risk factor of a positive smoking status was present in only one patient. The mortality rate was 33%.

Table II shows a detailed description of the nine cases. As seen here, seven of

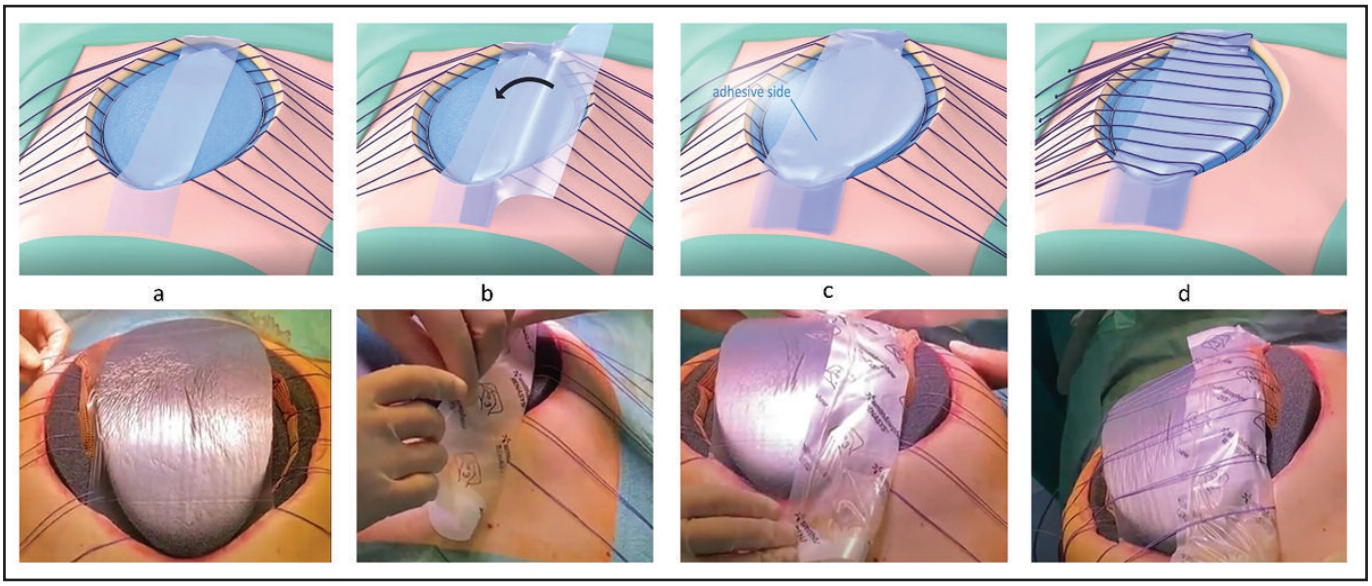

Figure 2. Airtight sealing for NPWT Part 1 (courtesy of Fasciotens GmbH and Department for General and Abdominal Surgery, Maria-Hilf Hospital, Brilon, Germany)
First Row: Schematic illustration showing the application of the adhesive dressing. Second Row: Corresponding intraoperative photograph.
a - A broad strip of adhesive dressing is placed on the medial foam including a small part of the skin cranially and caudally.
b - A second strip of adhesive dressing is applied to half of the middle part of the foam,
c - The second half is folded over itself towards the middle and the adhesive side faces upwards.
d - The traction sutures of one side are moved medially under tension onto the adhesive side of the adhesive dressing.

the patients had an underlying disease in the field of abdominal surgery. The two cases from the vascular department were admitted as emergencies with a perforated abdominal aortic or iliac aneurysm undergoing an open vascular reconstruction. In most cases, the reason to start an OA was abdominal compartment syndrome. The abdominal-surgical patients were septic at the beginning of the open abdomen therapy, in contrast to the vascular group, where the abdominal compartment syndrome was caused by a massive fluid resuscitation due to the great blood loss. The fascial dehiscence at the beginning of the OA ranged between 8 and 20 cm (median 14 cm) and the duration of VMMFT varied between 2 and 14 days (median 6 days). Definitive and direct fascial closure was achieved in seven of the nine patients. One patient was bridged using an OviTex Biologic Reinforced Tissue Matrix (TelaBio®, Malvern, PA, USA). In another case, closure would have been achievable, but the patient died due to therapy limitations because of short bowel syndrome and a poor prognosis. All patients were treated in the ICU and were sedated and intubated during OA. Intensive Care treatment

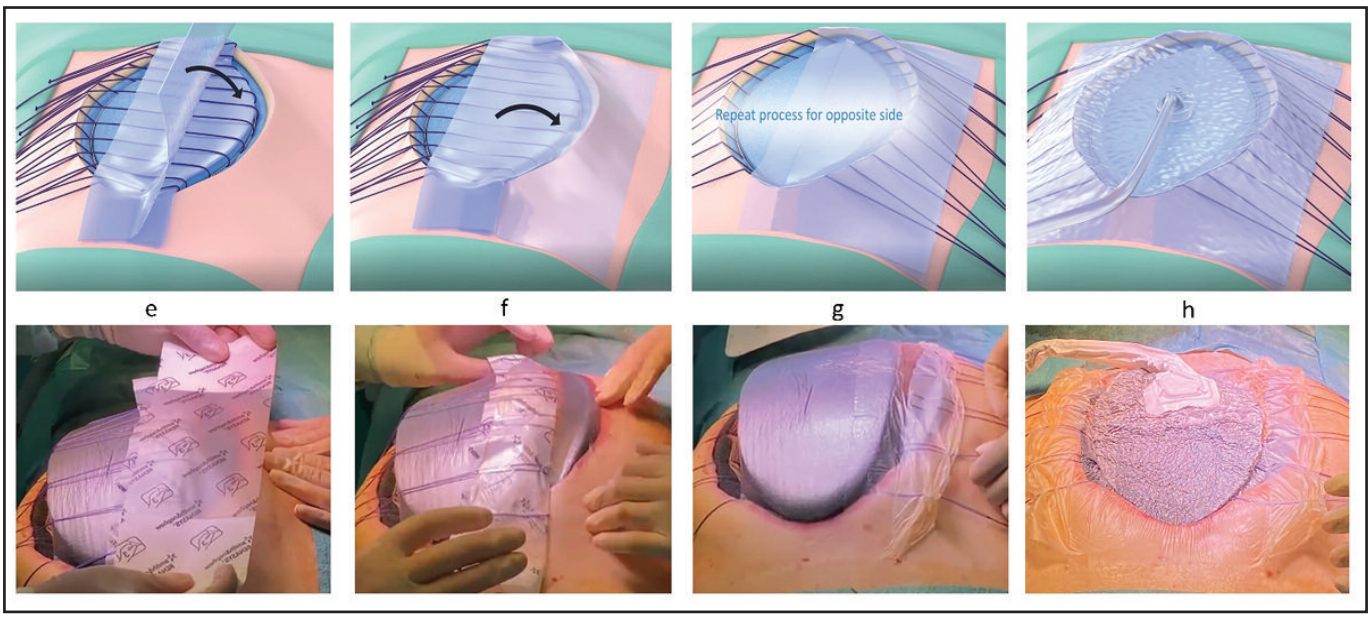

Figure 3 Airtight sealing for NPWT Part 2 (courtesy of Fasciotens GmbH and Department for General and Abdominal Surgery, Maria-Hilf Hospital, Brilon, Germany)
First Row: Schematic illustration showing the application of the adhesive dressing. Second Row: Corresponding intraoperative photograph.
e - Another strip of adhesive dressing is applied to the exposed adhesive side
f - The strip then sandwiches the traction sutures and is applied laterally to the skin.
g - The process is repeated for the other side.
h - The trackpad is placed centrally on the adhesive dressing. A constant negative pressure according to recommended hospital policy is applied.

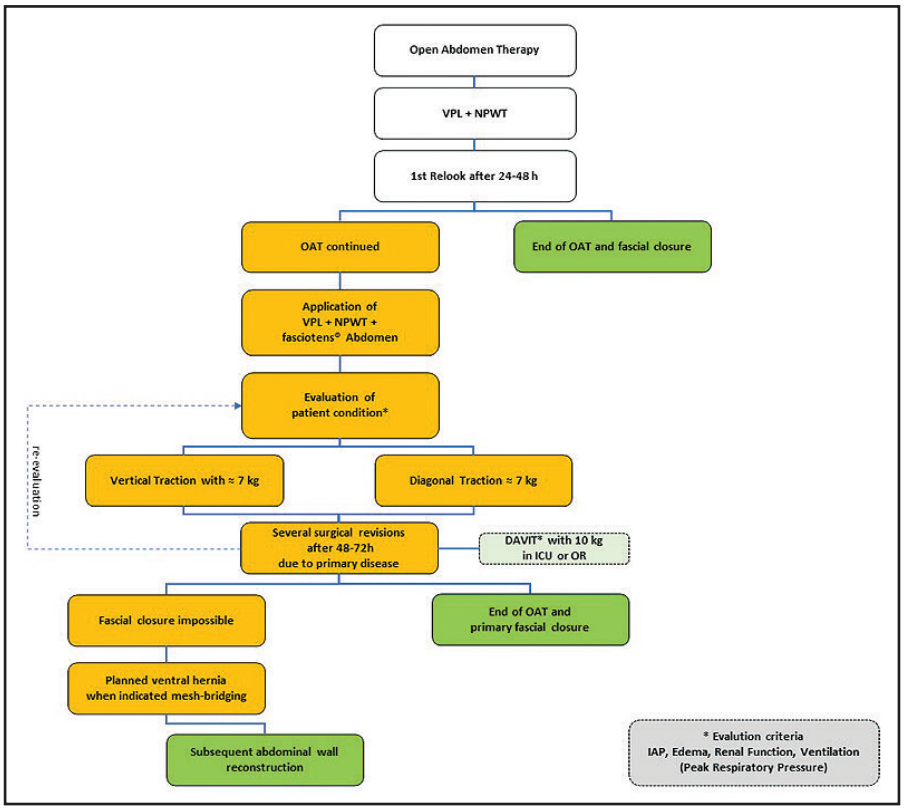

Figure 4. Algorithm for VMMFT using a device to apply controlled and reproducible traction to the abdominal wall (fasciotens®Abdomen) in combination with NPWT. The VMMFT algorithm is adapted from the Koblenz algorithm.[8,15]

was carried out according to the clinic standards. No acute complications, related to VMMFT, occurred.

During OA, no fistula formation was observed. No wound-healing disorders or burst abdomen occurred directly after closure of the abdomen. Three patients died due to other systemic organ failure during the same hospitalization. No standardized follow-up data were collected.

DISCUSSION

In the present cases, an OA was established for various reasons. According to the literature, an OA with a duration of more than 8 days without DFC results in significantly increased rates of complication and mortality.[20] The main complications during OA are multiple organ dysfunction syndrome (30-40 %), enterocutaneous fistula (2-25 %), abdominal abscess (83%), and incisional hernia (25%).[21] Although OA can be lifesaving, the mortality rate is still quite high (10 – 56 %).[21] The longer the OA remains, the more unlikely a DFC becomes.[4]Therefore, prompt closure of the abdomen should be performed as soon as the acute situation is resolved.

In our patient group, DFC was achieved in seven of nine cases (fascial closure rate 78 %). In one case, the fascial traction device was applied only after more than a week of OA using NPWT. When VMMFT was applied due to the simultaneously increasing edema, a gap between the fascial edges of more than 20 cm was present. Although sufficient intra-abdominal space was created by vertical traction during the extensive edema, diagonal traction did not achieve a sufficient increase in the length of the lateral abdominal wall. At the end of the OA, an 8 cm-wide defect remained. The defect was bridged using an OviTex Biologic Reinforced Tissue Matrix (TelaBio®) as an Inlay mesh. In the other case, DFC would have been achievable, but the patient died due to therapy limitations because of short bowel syndrome and a poor prognosis.

By using a commercially available NPWT in combination with a VPL, adhesions and fistulas were prevented in all patients. The VPL was proven to significantly reduce the risk of enteroatmospheric fistulae.[7] By using a combination of NPWT and VMMFT applied by fasciotens®Abdomen, it was possible to respond dynamically to the changing intraabdominal conditions. Starting from this point, the time to revision surgery could be extended in non-septic patients. Furthermore, a controlled adjustment of the fascial traction and a change of the traction direction from vertical to diagonal was possible without the need for surgical intervention. In our view, this is an advantage over the VAWCM approach.

In the first descriptions of MMFT, delayed DCF was achieved after a mean of 32 days (12d - 52d).[22] Regarding the latest systematic review of OA using VAWCM, the time until DFC was achieved varied between 7 and 32 days.[9] Other techniques like the ABRA system are associated with an average of 25 days of open abdomen treatment.[21] In our case series, the mean duration of OA was 9.6 days (3-16d). Fung et al. reported a mean time to fascial closure using VMMFT of 7 days.[13] Despite the low number of cases, our results imply that using VMMFT in combination with NPWT might reduce the duration of OA.

After starting with VMMFT in both hospitals, we aligned the OA treatment with the recommendations obtained using the Koblenz algorithm.[14] Following that, we adapted the Koblenz algorithm for use with VMMFT. We are convinced that a better outcome can be achieved by following an algorithm for OA that includes a re-look operation within 24-48 hours and early establishment of dynamic facial closure. This is especially important since it becomes more unlikely to achieve DFC after day 5 of OA or the third re-look operation.[4] Furthermore, the European Hernia Society recommends an early and direct closure of the white line to prevent hernia formation.[23,24]

Along with the established algorithm, diagonally-directed traction was used to facilitate myofascial medialization. To determine whether a strict vertical or diagonal traction can be applied, the following parameters should be considered: IAP, the extent of the edema, renal and lung function. As no exact ranges for the parameters can be given at this time due to the small patient group, some basis for decision-making can be made. Regarding IAP, we followed the recommendations of the Abdominal Compartment Society (WSACS).[25] For lung function, an algorithm proposed by Quintela et al. using the peak inspiratory pressure for large ventral hernias should be taken into consideration.[26] Nevertheless, the evaluation in our cases was always made in close cooperation with the ICU staff and anesthetists. By using our experiences from

IFT where the abdominal wall is stretched under relaxed patient conditions, the concept of DAVIT was carried out regularly for the last three patients in this cohort.[17] In our case series, all patients were kept sedated and ventilated during OA due to hospital standards and the critical illness of the patient cohort. Nevertheless, cases with awake patients have been described.[27] Our experience mainly depends on ICU standards and the patients' conditions and compliance.

VAWCM may be the most commonly used technique for dynamic fascial traction. VMMFT should be considered as the consequent evolution of mesh-mediated fascial traction. In our view, this is due to the ability to apply either vertical or diagonal traction with reproducible forces and the opportunity to adjust traction forces during treatment without returning to the OR. However, the duration also depends on the patient's condition and the reason for initially establishing an OA. Nonetheless, it appears to reduce the duration of OA, potentially resulting in cost savings regarding ICU time. Naturally, these findings should be verified in a larger patient group. This also applies to the selection of patients, as the manufacturer of the device only specifies a few contraindications (e.g., unstable thorax and pelvis). Future research is needed to determine which patients could benefit most from VMMFT.

STUDY LIMITATIONS

This was a retrospective analysis with data collected from the EHS registry for open abdomen looking at a heterogeneous group of patients. The proposed algorithm was only used in a small patient group and therefore further validation is needed. Patient-related outcomes such as quality of life and postoperative incisional hernia rates were not examined.

CONCLUSION

In the treatment of acute abdomen and ACS, OA is a life-saving measure, especially when a second-look surgery or multiple revision surgeries are necessary. Fascial retraction during open abdomen treatment is a significant risk for major complications in the further course of therapy. In our experience, the algorithm outlined above for OA using NPWT in combination with VMMFT is a promising and easy to introduce approach. We have experienced that the application of the fascial traction device as described above is easy to learn and does not need outstanding experience in abdominal wall surgery. STI

AUTHORS' DISCLOSURES

The authors declare that there are no conflicts of interest.

The animated images in Figs. 1, 2, and 3 are shown with permission of Fasciotens GmbH (Essen, Germany)

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