A new era in the management of open abdomen

Witsarut Jirapongsakorn, MD
Burapat Sangthong, MD
Department of Surgery, Faculty of Medicine
Prince of Songkla University

Introduction

Open abdomen (OA) is an important step of damage control surgery (DCS) in trauma surgery due to the improvement of patient outcomes. The purpose of DCS is to limit the operative time, permitting the patient to return to the intensive care unit for resuscitation. In general surgery, acute compartment syndrome (ACS) is a result of intra-abdominal injury (primary) or splanchnic reperfusion after massive resuscitation. This may include sepsis or pancreatitis. It causes patients to have a low urine output, as well as hypotension and an increase in ventilator pressure. Open abdomen for decompression, is also an essential treatment for in this category of patient.

The goal in the management of patients, after OA is closure of the fascial defect as early as stable clinical conditions allow, without ACS because the risks associated with OA include; fluid or electrolyte imbalance, systemic inflammatory response, gastrointestinal fistula and adhesions. (Table 1)

<table>
<thead>
<tr>
<th>Risks associated with open abdomen</th>
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<tr>
<td>Local effects</td>
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<tr>
<td>Gastrointestinal fistula formation</td>
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<tr>
<td>Intra-abdominal abscesses</td>
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<td>Abdominal infection</td>
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<td>Adhesions causing bowel obstruction</td>
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<tr>
<td>Adhesions precluding subsequent surgery and/or primary closure</td>
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<td>Fascial retraction</td>
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Table 1 Complications of the open abdomen technique

The traditional treatment to close the fascial defect is to make a skin graft on the granulated open abdomen (Fig. 1-A) resulted as a ventral hernia (Fig. 1-B). Abdominal wall reconstruction is carried out within the next 6-12 months by; evaluation of sagging by pinch testing. However, this approach is associated with the increased cost of medical care, adhesions, atrophic muscle and a risk of enterocutaneous fistula. Cheatham et al. reposted significantly decreased perceptions of physical, social, and emotional health in patients awaiting abdominal wall reconstruction.

Figure 1: Mature granulation tissue in an open abdomen, which is then covered with a split-thickness skin graft.
Recently, the temporary abdominal closure (TAC) technique has also been an important treatment to help the patient with open abdomen for above reasons. (An indication for TAC is provided in Table 2.)

### Indications for Temporary Abdominal Closure

<table>
<thead>
<tr>
<th>Condition</th>
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<tr>
<td>Damage control</td>
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<tr>
<td>Severe hemorrhage</td>
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<td>Hypothermia, coagulopathy, acidosis</td>
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<td>Delayed definitive operation secondary to patient’s physiologic state</td>
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<td>Intra-abdominal hypertension or compartment syndrome</td>
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<td>Questionable visceral viability</td>
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<tr>
<td>Planned acute reoperation</td>
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<tr>
<td>Severe intra-abdominal sepsis</td>
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<td>Triage</td>
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Table 2 Indications for temporary abdominal closure

An ideal TAC should have the following concepts (8):
- Easily contain the bowel and abdominal viscera
- Allows room for expansion of abdominal cavity
- Protects the fascia and viscera and prevents fascial retraction
- Evacuates infectious materials
- Contains and quantifies fluid loss
- Prevents adhesion
- Has a good primary fascial closure rate

### Temporary abdominal closure technique

The management of the open abdomen has been developed for more than 30 years. (Table 3)

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Mechanism</th>
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<tbody>
<tr>
<td>Vacuum-assisted Closure</td>
<td>A perforated plastic sheet covers the viscera then a reticulated polyurethane sponge is placed over the plastic.</td>
<td>The negative pressure supplied by the suction pump keeps constant tension on the fascial edges and helps to resolve edema.</td>
</tr>
<tr>
<td>Vacuum pack</td>
<td>A perforated plastic sheet covers the viscera then damp surgical towels or laparotomy pads and surgical drains are placed.</td>
<td>The negative pressure keeps constant tension on the fascial edges and collects an excess fluid.</td>
</tr>
<tr>
<td>Artificial burr (Wittmann patch)</td>
<td>Two opposite Velcro sheets (hooks and loops) are sutured to the fascial edge and connected in the middle of abdomen.</td>
<td>This technique allows for easy access and reapproximation of the fascial edges.</td>
</tr>
<tr>
<td>Dynamic retention sutures</td>
<td>The viscera are covered with a barrier sheet. Horizontal sutures are placed through a large-diameter catheter and through entire both sides of abdominal wall in an extraperitoneal plane.</td>
<td>These sutures keep tension and may be gradually tightened to allow staged reapproximation of abdominal wall. May be combined with a vacuum system.</td>
</tr>
<tr>
<td>Plastic silo (Bogota’ bag)</td>
<td>A sterile X-ray film cassette bag or sterile 3-L urology irrigation bag is sutured between the fascial edges or the skin.</td>
<td>An easy technique that allows for easy access, protect the abdominal content and prevent retraction of fascial edge.</td>
</tr>
<tr>
<td>Mesh/sheet</td>
<td>An absorbable or nonabsorbable mesh or sheet is sutured between the fascial edges.</td>
<td>As swelling resolved, the mesh or sheet may be reduced in size to allow for reapproximation.</td>
</tr>
<tr>
<td>Loose packing</td>
<td>The abdominal cavity is packed then the fascial defect is covered by standard wound dressing only.</td>
<td>This technique is simple but has no prevention of fascial retraction.</td>
</tr>
<tr>
<td>Skin Approximation</td>
<td>The skin is closed over the fascial defect with towel clips or a running suture.</td>
<td>It can provide the protection of viscera but the towel clips obstruct radiological imaging and do not prevent fascial retraction or IAH.</td>
</tr>
<tr>
<td>Zipper</td>
<td>A mesh or sheet with a sterilized zipper is sutured between the fascial edges.</td>
<td>This technique is comparable to the mesh/sheet and allows for easy access and prevention of retraction of abdominal wall.</td>
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Table 3. Various methods of temporary abdominal closure IAH; intra-abdominal hypertension
**Simple packing (Fig. 2)**
This surgical technique was the most commonly used technique in the 1980s and was performed by placing moist and sterile gauzes directly over the abdominal contents. Previous studies\(^1\) reported morbidity and mortality rate decreased but there were problems with evisceration, fluid and electrolyte loss as well as fistula formation.

**Skin-only closure (Fig. 3)**
This technique was also a commonly used technique in previous eras by, approximating the skin with towel clips or sutures, which were placed 2-3 cm apart. It is the most rapid of the temporary abdominal closure techniques. However, this type of technique frequently resulted in ACS 13-36% due to visceral edema\(^2\). Skin injury from retraction may also occur and produce a problem in later abdominal wall reconstruction\(^2, 13\). Today the skin-only closure is used for two scenarios. One, as a temporary measure in the operating room to resuscitate to a second look operation, and secondly as a trial of fascial approximation\(^2\).

**Plastic silo (Bogota bag) (Fig. 4)**
This technique can be used as a first-line treatment for TAC by; suturing a non-permeable barrier, including sterile plastic sheeting, silo or a 3L genitourinary irrigation bag, to the skin or fascia. Advantages are that it is easy to apply, there is also a prevention of evisceration and desiccation\(^2, 6, 13\). The rates of primary closure range from 12-82% but it can be time-consuming and might not prevent adhesions, fluid loss or the retraction of muscle. Entericcutaneous fistula rates range from 0-14.4%\(^6, 14\). Manterola et al.\(^15\) found that 60 % of patients, who undergoing relaparotomy followed by, a laparostomy using the Bogota bag, developed a ventral hernia within a 48 month follow-up.

**Mesh (Fig. 5)**
There were reports in the use of absorbable and permanent synthetic repair materials for patients with TAC by, suturing prostheses to the fascial edges, then gradually tightening these during reoperation\(^3\). Permanent synthetic mesh was sutured to both the fascial edges to protect abdominal wall tissues from injury when repetitive surgical procedures were performed as well as which to prevent any retraction of the fascia. Polypropylene mesh (PP, Martex) with porous structure is appropriate for growth of microvascular vessels and convenient for topical growth factor. Yuan et al.\(^16\) reported the microvascular densities, thickness of granulation tissue, and fibroblast counts were the highest for polypropylene mesh closure when compared with polyethylene sheeting. Although, the primary closure rates are ranged from; 33-89 %, fistula rates range from;6.6-14.7%\(^17-20\). Hence, a non-adherent barrier should be placed between the viscera and fascia to prevent
formation of fistulas. Some microporous materials such as; polytetrafluoroethylene (ePTFE), were developed for preventing adherence to tissue but there were still high infection rates. Thus, both PP and PTFE should not be placed in a contaminated environment. Absorbable mesh such as; polyglactin 910 (Vicryl) and polyglycolic acid (Dexon), was later developed. These materials have large interstices that allow for drainage, so there are more resistant to infection. They also stimulate fibrous granulation tissue along with epidermal cell proliferation. However, there were reports in fistula formation rates, which ranged 5-11% and intra-abdominal abscesses.

**Wittmann patch (Fig. 6)**

This technique is also called “artificial burr” and consists of a hook and loop sheet (Velcro). This technique is performed by placement of a non-adherent barrier, which has multiple holes, allowing for egress of fluid between the bowel and parietal peritoneum (Fig. 6-A). The Wittmann patch is sewn to the opposing edges of the fascia, then brought into the midline of the abdomen to apply pressure (Fig. 6-B). Peak airway pressures are also checked to ensure that they do not increase > 10%. Sterile gauzes and drains are applied (Fig. 6-C). Adhesive draping is used to seal the abdominal wall (Fig. 6-D). The suction dressing is changed, and the patch is also tightened every 1-3 days. The advantages of the Wittmann patch are to decrease abdominal distension, gradually approximating the fascia, rapid and safe reentry into the abdomen and as well as which to prevent loss of abdominal domain. Previous studies showed the primary fascial closure rates range from; 78-100%. The overall complication rates remain relatively low and the fistula rates are; 0-4.2%. However, it is still expensive and also perceptible tissue injury and subject to infection.

**Vacuum-assisted closure (VAC) or Vacuum-pack closure (Fig. 7)**

This was described by Barker et al. in 1999 by, creating a negative-pressure bag to decompress abdominal pressure, preventing adhesions and minimize retraction of abdominal fascia, or loss of abdominal domain. The key features of VAC mostly include:

- **A fenestrated inner layer**: An pliable material that is placed on top of the viscera to prevent adhesion formation, this also contains the abdominal contents and allows for fluid movement.

![Figure 7: Barker vacuum-pack technique](image)

![Figure 6: Wittmann patch technique](image)
enterocutaneous fistula and intrabdominal abscess are about 4.5%.

Currently, there are several commercial equipments available. **KCI ABthera negative-pressure dressing** (Fig. 8) is also commonly used as a negative-pressure dressings systems. It consists of a large visceral protective layer, which includes a polyurethane film-covered central sponge, with six arms of polyurethane sponge that can drain fluid from the gutters, the pelvis and loops of the bowel. Other parts of the system include a sponge that occupies the defect between the two edges of the open abdominal wall, then an adhesive drape is placed to create an airtight seal. Recently, Cheatham et al.28, who conducted the comparison between Barker’s vacuum-packing technique and the ABThera system, found that the ABThera System had a significantly higher 30-day primary fascial closure rate as well as a lower 30-day mortality rate. In contrast, the study, which was conducted by Kirkpatrick et al.29, showed no difference between patients using the ABThera or Barker’s vacuum pack, as to the improvement in peritoneal fluid drainage, fascial closure rates, or markers of systemic inflammation. However, it still costly due to the high costs of commercial dressing, and the system cannot be placed over a protruding viscera. There are some studies30 that reported if; the treatment exceeds 3 weeks, it is also very difficult to close the fascia.

**Vacuum-assisted wound closure and mesh-mediated fascial traction (VAWCM)** (Fig. 9)

Because of marked swelling to the viscera, a longer treatment period is necessary. There is a novel technique, for a late closure of the open abdomen, which was described by Petersson et al.31. After placing a perforated, plastic sheet on the abdominal contents, two PP meshes are sutured to the fascial edges. Thee are then, retracted and sutured into the midline with No.0 monofilament, as a continuous technique. The foam, or gauzes along with the suction drains are then covered on the top of the meshes after which, an adhesive drape is applied. Suction drains are connected with a suction device with a continuous, topical negative pressure of 100-150 mmHg. This VAC is changed every 2-3 days and the meshes are tightened. Previous studies32, 33 found that the delayed fascial closure rate ranged from; 78-89%, and that the enterocutaneous fistula rate ranged from; 7-12%. Although, Bjarnason et al.34, who studied in one-year follow-up after open abdomen therapy with vacuum-assisted wound closure and mesh-mediated fascial traction, found that the incidence of incisional hernia, after 1 year in patients with VAWCM was high, most of these cases were small and asymptomatic hernia was corrected with minimal surgical repair. In conclusion, the advantage of the VAWCM technique is a synergistic method to facilitate closure of the abdomen. It provides for a entirely clean abdominal cavity, whilst also providing the abdominal wall to move toward the midline, but it requires the need for trained personnel to conduct dressing changes and perform fascial traction.

Figure 8: **KCI ABthera negative-pressure dressing**

Figure 9: **Vacuum-assisted wound closure and mesh-mediated fascial traction technique**
Sequential fascial closure
This technique is the modified method proposed by Miller et al. After stabilization of the patient’s clinical conditions, the sequential closure technique can be performed. Multiple white sponges are overlapped on top of the viscera but beneath the fascial edges and also stapled together using a skin stapler. The fascia is sutured with No.1 polydioxanone sutures (PDS) as an interrupted technique. The PDS are full-thickness fascial bites, (>1.5 cm) placed about 5 cm apart in an interrupted fashion. An adherent clear plastic VAC covering is then placed over the all of the white sponges, and adjacent to 5-10 cm of skin (Fig. 10-A, B). The central part of the clear plastic is removed, whilst the remaining plastic is adhered to the skin (Fig. 10-C). Black, VAC sponges are then placed on top of the white sponges (Fig. 10-D, E). Standard suction drains along with occlusive dressing are placed (Fig. 10-D, E). VAC is changed every 2 days by replacement of the black and white sponges. The fascia is also sutured with No.1 PDS in an interrupted technique from both, superior and inferior directions without re-exploration of the abdomen. Burlew et al. reported that 100% patients, using the sequential closure protocol after DCS, in a five-year study period had fascial closure without complications. Moreover, the element of timing to return to the operating room (OR) is important because two-thirds of the protocol failures in this study were due to a return to the OR of more than 48 hours that provided for only 55% of the patients fascial closure.

Figure 10: Sequential fascial closure
Tension suture technique
There are various strategies to describe this technique for prevention of fascial retraction. Timing of the application after, the resolution of systemic inflammatory response and visceral edema, is important due to; low frequency of intra-abdominal pressure. A VAC technique may be used for this reason. Before, application of this technique the surgical wound is debrided and adhesions are carefully dissected. A non-adherent sheet is placed to cover the viscera. Two fascial edges are sutured with No.1 PDS in a continuous fashion. The interval between the loops and the depth the sutures are approximately 2 cm. The sutures are also locked with metal bullets. Finally, a transparent occlusive dressing (Fig.11) or VAC dressing is placed on the wound. The sutures are tightened every 2-3 days by sliding the bullet along the line, this is accomplished without removing the sutures. Gäddnäs et al. who, described this method, found that 81% of patients had fascial closure without bowel fistula or erosion from tension of the sutures. Moreover, Kafka-Ritsch et al. found that 86% of critically ill patients, with dynamic retention sutures and topical negative pressure, could achieve fascial closure.

Nowadays, dynamic retention sutures technique is developed as commercial dressings for ease of use. These are called “Abdominal Reapproximation Anchor (ABRA)”. They are designed to allow gradually re-approximation of abdominal muscles coupled with fascia into the midline. After, the surgical wound is surgically debrided and adhesions are also dissected, a perforated silicone sheet is placed between the viscera and abdominal wall. Midline crossing elastic bands (elastomer) are inserted through the incised full-thickness of the abdominal wall approximately 5 cm from wound margin, and aligned about 3-5 cm apart along the wound length. The button anchors are used to fix the elastomer at the insertion site, this keeps the tension. An adhesive button tail is attached to the anchor to prevent its displacement or tilting (Fig. 13). The monitoring of the tension is by means of the black-and-white calibration marks. Initial tension should be set at approximately a 1.5 to 2 x stretch length of the calibration marks. Oclusive dressing or VAC is applied on the remaining defect. Dressing changes are performed as standard practice with abdominal wall massage. An elastomer tension is adjusted as physicians need to maintain the tension. Reimer et al. showed that 61% patients achieved delayed primary closure, but the rates of hernia formation were 26%, and the rates of enterocutaneous fistula formation were 9%. Verdam and Haddock, who combined this technique with VAC dressings, found that delayed primary closure in patients with OA could be achieved in 88% and 100% respectively. However, the risk of hernia development was 25% and 33% respectively, it was depended on the extensive preoperative damage and infection of the fascia.
Evidence from temporary abdominal closure in the present period

Recently, an attempt to reduce the time from a TAC, to primary fascial closure in patients with OA resulted in the development of various techniques of TAC as previously mentioned. Regner et al.\textsuperscript{43} suggested that there was a bimodal distribution of patients with TAC. The first were able to close the abdomen within 4-7 days, giving a high rate of primary closure, while the second group had a delayed (20-40 days) closure, these having a lower, overall rate of closure. So, if closure of the abdomen within 7 days, is not obtained progressive, fascial closure equipment may be needed such as; Wittmann patch, to obtain subsequential, fascial closure.

There are multiple studies, which evaluate the effectiveness of several TAC techniques. In a systemic review study, which was conducted by Quyn et al. in 2012\textsuperscript{44}, it was found that the Wittmann patch and VAC offered the best outcome in the group of non-septic patients but a high delay in closure coupled with a low mortality rate could be found when VAC was used on septic patients. These results were similar to the results of a systemic review study, which was described by Atema et al.\textsuperscript{45}. They conducted the study in non-traumatic patients with OA and found that the highest weighted fascial closure rate was reported in groups of VAC with continuous mesh or suture mediated fascial traction (73.1%) and dynamic retention sutures (73.6%). The fistula risk also dropped to 5.7% when VAC was combined with continuous mesh or suture mediated fascial traction. However, the overall quality of the available evidence are still poor due to retrospective studies and problems in data collections as to there are no definite conclusion which type of TAC works best in recent times.

Other general management of patients with OA, concluded that nutritional support is also important for recovery of the patient as well as overall wound healing. From previous studies\textsuperscript{46-48} it was suggested that it was safe for enteral feeding within 36 hours to 4 days due to improvement in rates of fascial closure and infectious complication by adding 2 g of nitrogen for every liter drained from the open abdomen\textsuperscript{2,49}.

After normalization of the patient’s physiology coupled with and good nutritional support, physicians can close the abdominal defect, which has a small gap, approximately 3 -7 cm. The methods for definitive abdominal reconstruction in addition to the choice of technique is dependent on; different patient factors, defect sizes, and abdominal structures.

In conclusion

- Damage control surgery or open abdomen surgery is an important procedure in trauma and general surgery. The goal of treatment is to resuscitate and should be available to ensure the fascial is closed as soon as possible. Primary due to avoiding any long-term complications.
- Several techniques of temporary abdominal closure had played an essential role for the prevention of intra-abdominal adhesion, infection and retraction of abdominal fascia, so as to achieve delayed primary fascial closure. Decision making methods are very much dependant on physician-patient factors and hospital supplements. After, failure to close the abdomen within 5-7 days, the physician should consider bridging devices. A review of recent studies suggests that the Wittmann or VAC can be available for used on TAC for non-septic patients but VAC with continuous mesh or suture mediated fascial traction is more suitable in septic patients.
- Nutritional support should also be considered by; adding 2 g of nitrogen for every liter drained from the open abdomen, within 36 hours up to 4 days.