Not so fast to skin graft: Transabdominal wall traction closes most ''domain loss'' abdomens in the acute setting

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BACKGROUND: Damage-control laparotomy (DCL) has revolutionized the surgery of injury. However, this has led to the dilemma of the nonclosable abdomen. Subsequently, there exists a subgroup of patients who after resuscitation and diuresis, remain nonclosable. Before the adoption of our open abdomen protocol (OAP) and use of transabdominal wall traction (TAWT), these patients required skin grafting and a planned ventral hernia. We hypothesize that our OAP and TAWT device, which use full abdominal wall thickness sutures to dynamically distribute midline traction, achieve an improved method of fascial reapproximation.

METHODS: From 2008 to 2011, all DCL and decompressive laparotomy patients in our urban trauma center were managed by our OAP. Thirty two were noncloseable "domain loss abdomens" after achieving physiologic steady state and near dry weight. All patients received the TAWT device when near dry weight was achieved. Wound size, days to closure, days to TAWT, and TAWT to closure were tracked.

RESULTS: During this 36-month period, OAP/TAWT was applied to 32 patients. All patients demonstrated domain loss precluding fascial closure. Average wound size was 18.5-cm width by 30.5-cm length. Mean time DCL surgery to TAWT was 9.5 days. At time of placement, TAWT decreased initial wound width by an average of 9.8 cm (51.4%). Patients returned to the operating room for tightening/washout an average of 2.2 times (excluding TAWT insertion and final closure operations). Mean time TAWT to closure was 8.7 days. Mean time from admission surgery to primary closure was 18.2 days. All patients achieved primary fascial closure using this method without components separation or biologic bridge operations.

CONCLUSION: OAP/TAWT has revolutionized the way we manage "domain loss" open abdomen patients and has virtually eliminated the acceptance of planned ventral hernia. TAWT consistently recaptures lost domain, preserves the leading fascial edge, and eliminates the need for biologic bridges, components separation, or skin grafting. (*J Trauma Acute Care Surg*. 2013;74: 1486–1492. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Therapeutic study, level III.

KEY WORDS: Transabdominal wall traction (TAWT); damage-control laparotomy (DCL); planned ventral hernia (PVH); open abdomen protocol (OAP).

Primary closure of the abdomen following damage-control laparotomy (DCL) is often not possible, resulting in the implementation of planned ventral hernias (PVHs) or the use of biologic closure materials.[1] Early treatment of the open abdomen consisted primarily of negative-pressure dressing (NPD) placement. This allowed for egress of excess abdominal fluid and served as a bridge to fascial closure or split thickness skin coverage.[2–7] Subsequent advances in abdominal closure focused on increasing medial traction of the abdominal wall using a number of methods including silastic bands, hook and loop fascial patches, and retention sutures.[8–10] With these techniques, rates of abdominal closure improved. Most recently, Burlew et al.[11] reported a method of partial abdominal closure, yielding a 100% success rate for their cohort of DCL patients who were maintained on the operative protocol. A 55% rate of closure was reported for patients who were not maintained on protocol.

We report our experience with a modification of the Wittmann patch (WP) closure. Rather than suturing the WP directly to the medial fascia, the device is anchored to the underside of the abdominal wall, lateral to the rectus sheath, using external bolsters. We hypothesize that this technique more effectively distributes medial traction to the external obliques, demonstrated by progressive shortening of the wound's width over time. In doing so, we believe this technique optimizes the patient's probability of successful fascial reapproximation.

PATIENTS AND METHODS

Patients with an open abdomen following laparotomy are temporarily closed using NPD therapy. Following correction of the patient's base deficit, repeat laparotomy is performed within the first 72 hours. Patients with open abdomens following the

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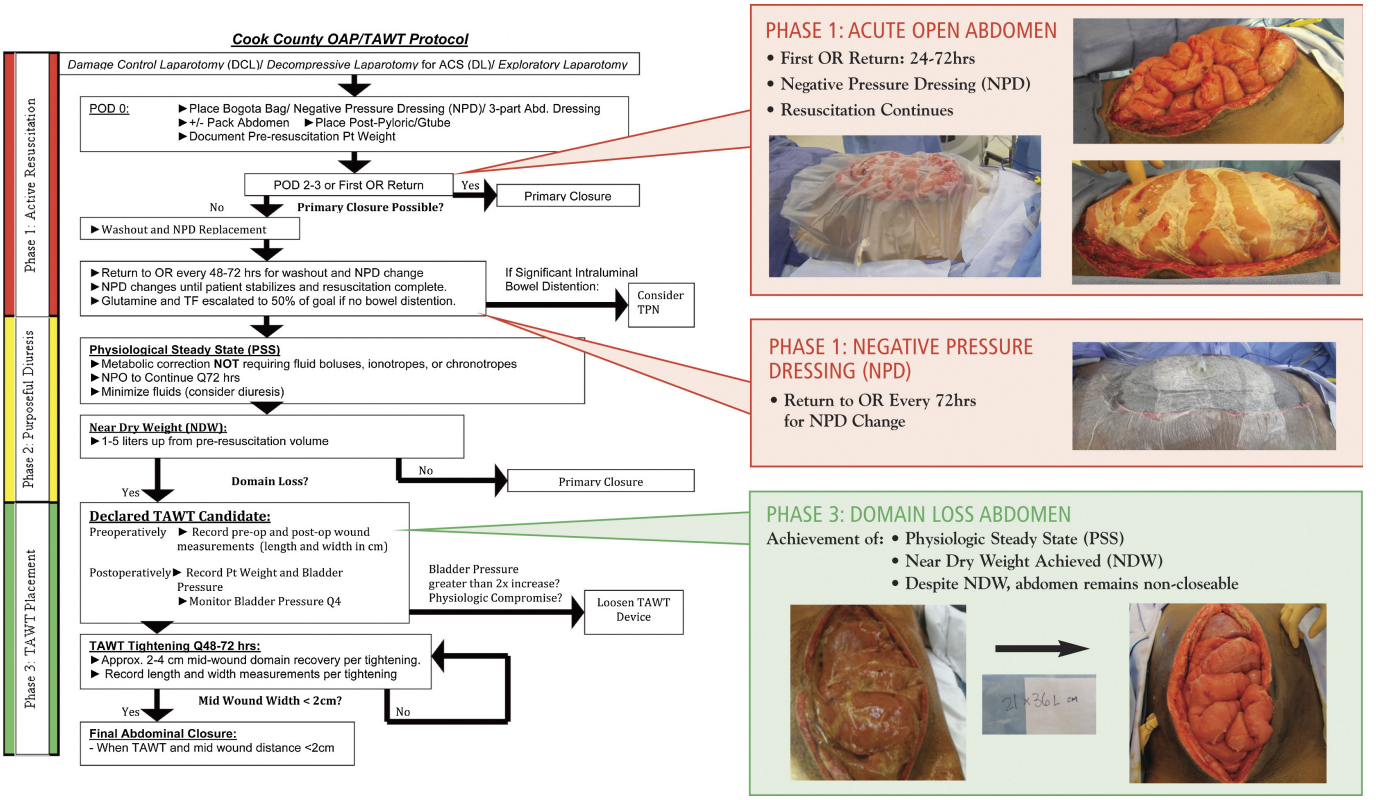

Figure 1. Cook County OAP/TAWT protocol.

second laparotomy are placed into an open abdomen protocol (OAP) (Fig. 1).

Patients return to the operating room for washouts and NPD changes at intervals of up to 72 hours. When no longer requiring fluid boluses, ionotropes, or chronotropes, patients are defined as having achieved physiologic steady state. At this time, glutamine and tube feeds are initiated via dobhoff tube. Fluid restriction and diuresis are implemented to attain a net-fluid balance of 5 L or less, defined as the patient's near dry weight (NDW). Patients who reach this threshold but remain unclosed are universally entered into the transabdominal wall traction (TAWT) protocol.

TAWT Technique and Device

The TAWT device and technique are adaptations of the previously described WP.[12] Materials consist of two hook and loop sheets (WP, Starsurgical, Burlington, WI), four padded aluminum, predrilled bolsters, #5 Ethibond polyester suture (Ethicon, St. Angelo, TX), a fenestrated plastic sheet (bowel cover), and several 8-inch by 8-inch pieces of adherent hydrocolloid dressing.

The anterior abdominal wall skin is covered by hydrocolloid dressings. Lateral to each side of the abdominal wall defect, two 1-inch wide by 9-inch long, semirigid, padded bolsters are placed over the hydrocolloid dressing. These bolsters are placed at the lateral side of the rectus muscles, on both sides of the wound. Care is taken to remain lateral, to avoid the vascular bundle within the muscle. A set of hook/loop sheets 30 cm by 10 cm are placed into the abdomen as an underlay abutting the peritoneal underside of the abdominal wall. The loop sheet is placed facing up, and the hook sheet is placed facing down. The hook and loop sheets are fixed to the

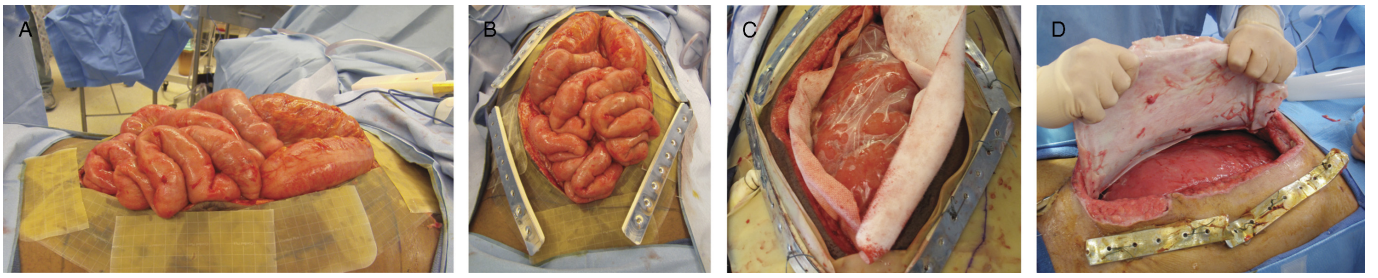

Figure 2. *A*, TAWT system: Skin protective hydrocolloid dressings applied; *B*, TAWT insertion: bowel protection barrier and skin protecting bolsters applied; *C* and *D*, TAWT insertion: hook and loop sheets placed as underlay.

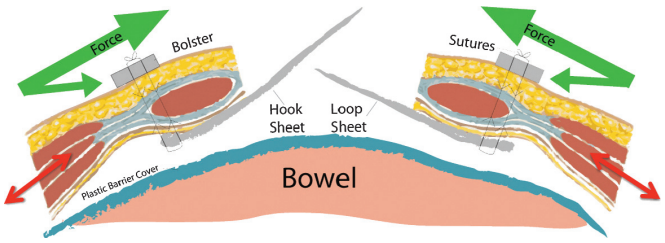

Figure 3. Schematic of forces. Sutures tether the bolsters to lateral edges of the recti. Traction is applied via tightening the hook and loop sheets (*gray*), resulting in an overall dynamic, medial force (*green arrow*), which is distributed across the entire abdominal wall.

underside of the abdominal wall by #5 polyester sutures running parallel to the vascular bundle, at the lateral edge of the rectus sheath (Fig. 2). The sutures penetrate all layers of the abdominal wall, effectively sandwiching it between the overlying bolsters (Fig. 3). A thin, fenestrated plastic barrier is placed over the abdominal viscera to provide protection to the viscera and inhibit their fusion to the underside of the abdominal wall. Hands are placed on both sides of the external lateral abdominal wall, and medially directed force is applied bilaterally. Simultaneously, the hook sheet is lifted medially and anteriorly while the loop sheet is pressed medially and posteriorly. They are then adhered to each other to fix the position of the abdomen (Fig. 3). An NPD is then applied above the hook and loop sheets. The TAWT system now applies isometric traction for a period of 48 hours, allowing for myofascial release and subsequent relaxation and lengthening of the oblique muscles and surrounding connective tissue. The patient is then returned to the operating room, paralyzed and intubated. The hook and loop sheets are opened. The abdomen is washed out, the visceral protective barrier is rinsed or replaced, and the TAWT device is again medially tightened in the manner described previously (Fig. 4).

Every 48 hours to 72 hours, patients returned to the operating room for tightening of the TAWT device. The timing of each tightening is dictated by the condition of the patient, the operating room schedule, and needs of other service patients. The protocol is flexible in this regard and allows for the discretion and judgment of the attending staff. In the operating room, patients were paralyzed and intubated, then extubated following the procedure. Patients received enteral nutrition between all TAWT tightenings. When patients achieve a 2-cm midwound fascia-to-fascia width, their abdomen is closed. All primary fascial closures are reinforced and supported by either biologic mesh or prosthetic, absorbable mesh (Bio A WL, Gore Assoc, Flagstaff, AZ). When possible, the posterior rectus sheath is closed, and mesh is placed into the retrorectus space. If this is not possible, mesh is placed as an underlay or overlay to the anterior rectus sheath closure. Drains are placed above the mesh and below the anterior fascia. Skin is left open to close by secondary intention. Statistical analysis was performed with SPSS 15.0 (SPSS Inc., Chicago, IL).

RESULTS

Patients were enrolled into the closure protocol between March 2008 and November 2011. During this period, 137 DCL and 7 decompressive laparotomies were performed. The inciting event requiring laparotomy included penetrating trauma in 121 patients, blunt trauma in 21 patients, perforated viscus in 1 patient, and abdominal compartment syndrome in 1 patient (Table 1). Of these, 42 expired before fascial closure. No deaths occurred in patients after TAWT placement. Fifty-eight patients were closed primarily. From 2008 through 2009, before the formal adoption of the OAP/TAWT protocol, 12 patients were closed by other means including skin bridging, mesh bridging, split-thickness skin grafting, or component separation. After 2009, all patients who could not be closed primarily were entered into the OAP/TAWT protocol; alternative methods of closure were not used.

From 2008 through 2011, 32 patients entered into the TAWT protocol. Mean time from DCL to TAWT placement was 9.5 days (range, 1.0–39.0 days). At the time of placement, average wound size was 18.5 cm in width (range, 9.0–30.0 cm) by 30.5 cm in length (range, 12–40 cm). The initial placement of TAWT reduced the initial wound width by an average of 9.8 cm (52.9%). The midwound fascial width decreased an average of 2.8 cm with the first tightening. Patients returned to the operating room for tightening an average of 2.2 times (excluding TAWT insertion and final closure operation).

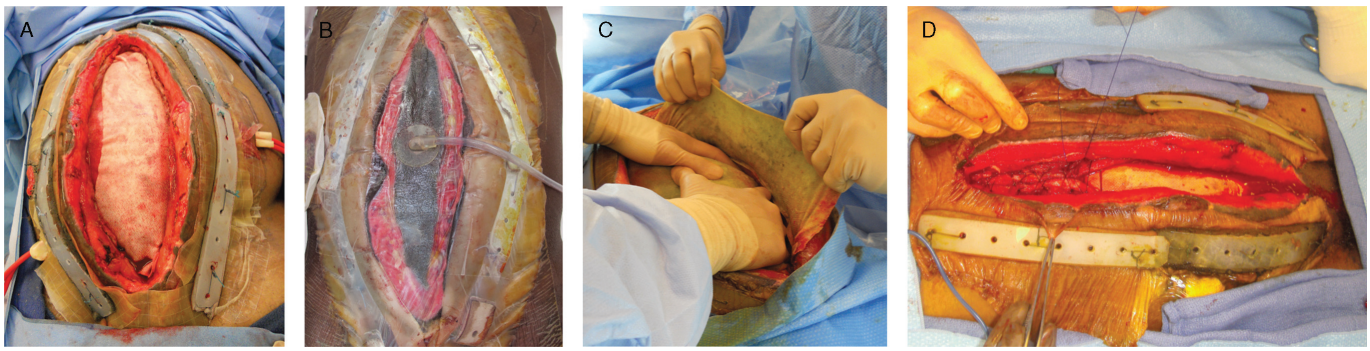

Figure 4. *A* and *B*, TAWT device inserted: defect reduced by 54%; *C*, TAWT tighten/washout: Return to the operating room every 48 hours to 72 hours. Expect domain recovery 2 cm to 4 cm each tightening; *D*, TAWT removal and primary closure: reinforced primary closure done in two layers with Gore Bio A inlay mesh when possible.

TABLE 1. Mechanisms of Trauma and Management of the Post-DCL/DL Open Abdomen

Mechanisms of Trauma (n = 144)			
DCL, n=137		Penetrating trauma, n (%)	121 (84)
		Blunt trauma, n (%)	21 (15)
		Emergency surgeries for perforated viscus, n (%)	1 (0.5)
DL, n=7		ACS cases, n (%)	1 (0.5)
Management of the Post-DCL/DL Open Abdomen (n = 144)			
Expired before closure, n (%)	42 (29)		
Non–domain loss closures, n (%)	58 (40)	Primary fascial closures, n (%)	58 (40)
Domain loss closures, n (%)	44 (31)	Non-TAWT closures, n (%)	12 (8)
		Primary fascial closures via TAWT system, n (%)	32 (23)

ACS, Abdominal Compartment Syndrome.

Before TAWT device placement, 7 patients (22%) were ventilator dependent; the remainder were intubated for the initial procedure. Twelve patients (37%) remained intubated following the procedure. Once the TAWT system was placed, 25 patients (78%) tolerated enteral feedings, reaching their caloric goals without requiring parenteral nutritional supplementation. The mean prealbumin score of these patients at admission was 13.0 mg/dL; at the time of abdominal closure, mean prealbumin was 10.0 mg/dL. Mean time from TAWT placement to primary fascial closure was 8.7 days (range, 1.0–18.0) (Table 2).

All patients who underwent TAWT placement achieved primary fascial closure. No component separation operations or bridging operations were performed. There were no PVH during this time. Mean hospital length of stay for OAP/TAWT patients was 44.1 days (range, 19–162 days). Four patients (12.5%) developed enterocutaneous fistulas. Two patients developed fistulas before the insertion of the TAWT device. The first fistula developed as an anastomotic leak following insertion of the device, while the second developed 3 weeks following TAWT removal. All continued to primary closure using TAWT despite the presence of the leak, and all leaks were managed via primary sump drains after abdominal closure. Three OAP/TAWT patients (9.4%) developed ventilator-associated pneumonias (Table 3). No patients developed intra-abdominal abscesses. No abdominal wall hernias were experienced at 6-month follow-up. Six patients developed small localized partial thickness skin breakdown or necrosis associated with placement of the TAWT device. There were no instances of dehiscence or evisceration.

DISCUSSION

The early 1990s began the era of the DCL where surgeons recognized the importance of the metabolic disturbances associated with shock and the role they played in mortality.[14–16] This led to the adoption of the abbreviated

TABLE 2. OAP/TAWT Detailed Procedural Results (n = 32 Unless Specified)

Mean no. days from initial operation to TAWT placement (range)	9.5 (1.0–39.0)
Mean no. days from TAWT placement to primary closure (range)	8.7 (1.0–18.0)
Mean no. days from initial operation to primary closure (range)	18.2 (7.0–57.0)
Mean Δ in width with TAWT placement, cm	9.8
Mean Δ in width with first tightening, cm	2.8 (n = 31)
Mean Δ in width with second tightening, cm	2.6 (n =21)
Mean Δ in width with third tightening, cm	1.5 (n = 9)
Mean Δ in width with fourth tightening, cm	1.0 (n = 3)
Mean Δ in width with fifth tightening, cm	0.5 (n = 1)
Patients with BMI < 30, n (%)	25 (78.1)
Patients with BMI > 30, n (%)	7 (21.9)
No. patients extubated before TAWT placement, n (%)	25 (78.1)
No. patients extubated during TAWT placement, n (%)	20 (62.5)
Mean wound width (range), cm	18.5 (9.0–30.0)
Mean wound length, cm (range)	30.5 (12.0–40.0)
Mean area index (range),* cm^2	564 (108–1,200)
Mean prealbumin level at admission, mg/dL	13 (5–28)
Mean prealbumin level at closure, mg/dL	10 (5–19)
Mean no. Tightenings (range)	2.2 (0–6)

*Since all patients were all Grade 4 in the System for Classification of Open Abdomen (Bjorck et al.[13]), Wound Area Index is used as an arbitrary integer denoting the product of length and width of the initial abdominal defect before TAWT emplacement, allowing comparison of wound area as though they were rectangular, understanding that most are in fact elliptical.

TABLE 3. Domain Loss TAWT Closure Patient Data (n = 32)

Mean age (range)	29.5 (16 to 59)
Mean ISS (range)	19.1 (4 to 75)
Mean APACHE II (range)	16.5 (5 to 34)
Mean PATI score (range)	38.8 (7 to 69)
Mean SOFA score (range)	6.7 (1 to 12)
Mean percent change of SOFA score in 24 h (range)	78.3 (−17 to 400)
No. primary fascial closures, n (%)	32 (100)
No. hospital days (range)	44.1 (19 to 162)
Incidence of fistula, n (%)	4 (12.5)
Incidence of VAP, n (%)	3 (9.4)

APACHE, Acute Physiology and Chronic Health Evaluation; PATI, Penetrating Abdominal Trauma Index; SOFA, Sequential Organ Failure Assessment; VAP, ventilator-associated pneumonia.

operation and the philosophy that it is better to cure in stages than to kill in one.[15] Hence, trauma surgeons began leaving more individuals open and mortality improved.[14] With this success came a population of patients who had persistently open abdomens caused by lateralization of the abdominal walls known as domain loss.[17,18] For many of these patients, PVH becomes the goal of therapy.[1]

Given the morbidity and costs associated with ventral hernias, various protocols have been developed with the goal of achieving primary closure for these patients. Central to any of these closure techniques is the midline fascial traction to counteract the lateral abdominal contracture that occurs when the abdomen is left open. A number of studies indicate that, in the absence of traction, connective tissue contracts.[19–21] From the histologic perspective, areolar connective tissue gradually reorganize in regions of contracture, becoming more dense. Once this occurs, motion in that area is restricted.[19] This shortening of connective tissue has been attributed to changes in the length of the collagen fibers themselves or to the metabolic response of fibroblasts.[19,22] The term *domain loss* describes this concept when applied to the lateral contractures of the abdominal wall.[20,21,23–25]

When an abdomen is left open, each side of the abdominal wall lateralizes owing to shortening and contracture from lack of opposing forces. Systems that place each side of the contracted abdominal wall under prolonged tension allow for elongation of connective tissue fibers and should reverse these changes. Such elongation has been attributed to separation of adjacent collagen fibers in the connective tissue meshwork.[19] This plasticity of connective tissue allows for elongation under moderate, prolonged tension and has been used in the methods developed for stretching contractures. By recognizing that abdominal domain loss is primarily the result of connective tissue contracture, we can see that it is preventable and reversible. In addition, evidence suggests that attempts to counteract loss of domain must focus on lengthening the contracted external obliques.[26–28]

Methods designed to counteract lateralization of the abdominal fascia have evolved significantly during the past 20 years. Initially introduced as a technique for temporarily closing and protecting the open abdomen, NPD may also augment abdominal closure rates. Brock et al.[2] published one such initial description of this method. A mesh is first sutured to each fascial edge. Sponges were then placed above the mesh and secured with adhesive plastic strips to create an air-tight seal capable of maintaining negative pressure when suction was applied to the apparatus. Early experiences with this technique were positive. Their later outcomes, reported as a retrospective review of 112 patients, included a 55% rate of primary closure and a fistula rate of 5%. A follow-up of this group's experience with 258 patients reported a closure rate of 69%, a fistula rate of 5%, an intra-abdominal abscess rate of 3.2%, and a bowel obstruction rate of 1.2%. Miller et al.[6] published a prospective report of their experience with vacuum-assisted fascial closure of 53 patients who required open abdominal management. Mean time to fascial closure was 9.5 days, with an overall fascial closure rate of 88%. One patient in this study developed an enterocutaneous fistula, while two experienced evisceration. Miller et al. suggest that the success of this modality may be related to its ability to augment diuresis from intra-abdominal tissue, thereby decreasing the volume of intra-abdominal contents. Second, the negative pressure may provide a form of medial traction on the abdominal wall.

More recently, success associated with a method of partial abdominal closure has been reported.[11,29] The technique involved an NPD as in the studies previously mentioned, with the addition of PDS (polydioxanone) retention sutures (Ethicon, St. Angelo, TX) through the abdominal fascia at 5-cm intervals. Patients return to the operating room at 48-hour intervals. The technique involves successive placement of sutures through the midline fascia every 48 hours until the abdomen is closed. The initial experience with this method reported a 100% closure rate, as did a subsequent study published in 2012. The success of this closure method seems to be highly correlated with adherence to the protocol, stipulating return to the operating room every 48 hours. The closure rate of patients whose care deviated from this parameter, however, was 55%.

We report a method of closure incorporating a hook and loop WP. In its initial description, the WP was secured to the opposing edges of the midline fascia. Results associated with this technique have reported closure rates as high as 100% for smaller series and near 80% for larger cohorts.[30] Our experience with WP closures was positive, but we noted significant damage to the midline fascia at the sites of attachment. Our concern was that the integrity of the tissue used for closure may be compromised. Furthermore, the traction needed for closure may be compromised if it is focused at suture sites rather than evenly distributed across the entire abdominal wall. Our solution is the TAWT system, which moves the attachment points of the WP lateral to the rectus sheath, preserving the midline fascia. Traction generated by the system is focused on stretching the obliques rather than the rectus musculature, which has not been implicated in lateralization of the abdominal wall. Furthermore, the bolsters sandwich the abdominal wall, providing a continuous length of attachment rather than discrete points at each suture. We believe this provides a more even distribution of medial abdominal wall traction. The consistent, progressive decrease in wound width following placement highlights this system's ability to generate traction through the lateral abdominal wall.

We report 100% rate of abdominal closure. Importantly, our success rate for abdominal closure is not restricted to a subgroup of patients. All patients who received a DCL during this period were closed either primarily or through the OAP/TAWT protocol. We also stress that the protocol does not require the operative team to adhere to a formal operative protocol. Trips to the operating room for tightening may take place at the discretion of the attending staff, highlighting the flexibility of this method of closure.

During the TAWT process, patients were intubated during the tightening procedures. Following the procedure, extubation was attempted on every patient, and success was predicated upon being able to protect one's airway and passing a spontaneous breathing trial. Between procedures, enteral nutrition was continued. Able patients were restarted on regular diets; those who remained ventilated or unable to take oral nutrition were given tube feeds. Specific tube feeds and regimen were based on recommendations of the trauma unit nutritionist. Of these, 78% of patients undergoing TAWT placement were subsequently able to tolerate goal rates of enteral feeding. In addition, prealbumin levels among our cohort of patients undergoing eventual TAWT placement averaged 13.0 at the time of admission and 10.0 after placement. Given the high rate of successful enteral feeds and the small difference in prealbumin levels, we do not believe that TAWT placement profoundly impacts nutritional status.

Complications experienced among our patients during TAWT closure included local skin necrosis and fistula formation. Necrosis of the skin occurred in six patients. In all of these patients, the areas were never greater than 1 cm in diameter and were rarely full thickness. Treatment consisted of local wound care and silver-sulfadiazine topical ointment. There were no superimposed infections.

Four patients developed enterocutaneous fistulas at various stages in the OAP, two patients before TAWT insertion, one patient during wall traction with TAWT, and one patient weeks following removal of the TAWT device. The percentage of patients developing enterocutaneous fistulas seems to be consistent with our rates before institution of the OAP/TAWT protocol. Given the relatively even distribution of fistulazation across all phases of the OAP and the similarity to our historical rates of fistula formation, we do not believe the OAP predisposes to this complication per se. The open abdomen, however, is a risk factor for a variety of complications including fistula formation. Theoretically, decreasing the duration of time to primary closure may decrease the incidence of fistula formation.[31] Our average time from initiation of the OAP to TAWT is 9.5 days and to closure was 18.2 days. A significant portion of this time is spent achieving NDW. We believe that achieving NDW before TAWT placement is imperative for optimal seating of the device. In our experience, patients with greater than 5 L net-fluid balance have the potential for significant abdominal wall edema. For this reason, we consider it necessary to delay TAWT placement until this swelling subsides, so the device does not loosen over time. By effectively sandwiching each side of the abdominal wall with bolsters, we believe that the TAWT device better distributes pressure across the abdominal wall, leading to more efficient transfer of medial tension to the external obliques rather than the local tissue that immediately surrounds the anchoring sutures. TAWT devices placed in patients who have yet to reach NDW may loosen as the abdominal wall edema subsides. In our experience, the sutures on loose devices become seton like and tear through the lateral fascia, destroying the tissue and less effectively decreasing the size of the midline wound.

CONCLUSION

Abdominal wall contracture and lateralization resulting in giant ventral defects are a common problem facing contemporary surgeons. By applying the physical medicine concepts of stretching and contracture release and management, we have demonstrated that abdominal domain loss is reversible when constant countertraction is applied to the shortened tissues. Protocolized application of TAWT allows any surgeon to close previously nonclosable, giant ventral abdominal defects.

AUTHORSHIP

A.D. was the primary author, inventor of the technique and protocol, and collaborating surgeon. He also performed the data collection. K.J. was the protocol developer (nutrition arm), reviewer, cowriter, protocol coauthor, and collaborating surgeon. T.V. was a research fellow and cowriter of the manuscript. He also contributed in the data collection and illustration/figure/table construction. S.K. was a cowriter of the manuscript, reviewer, and collaborating surgeon. F.B. performed the data collection and was a reviewer, protocol coauthor, and collaborating surgeon. F.S. performed the data collection and was a reviewer, protocol coauthor, and collaborating surgeon. S.P. performed the data collection and was reviewer and collaborating surgeon. D.W. performed the data collection and was reviewer, protocol coauthor, and collaborating surgeon. T.M. performed the data collection and was a reviewer and collaborating surgeon. K.N. performed the data collection and was reviewer, protocol coauthor, and collaborating surgeon.

DISCLOSURE

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