Linea Alba Fasciotomy: A Novel Alternative in Trauma Patients with Secondary Abdominal Compartment Syndrome

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Polytrauma patients needing aggressive resuscitation can develop intra-abdominal hypertension (IAH) with subsequent secondary abdominal compartment syndrome (SACS). After patients fail medical therapy, decompressive laparotomy is the surgical last resort. In patients with severe pancreatitis SACS, the use of linea alba fasciotomy (LAF) is an effective intervention to lower IAH without the morbidity of laparotomy. A pilot study of LAF was designed to evaluate its benefit in patients with SACS polytrauma. We conducted an observational study of blunt injury polytrauma patients undergoing LAF. Variables measured before and after LAF included intra-abdominal pressure (IAP, mmHg), abdominal perfusion pressure (APP, mmHg), right ventricular end diastolic volume index (RVEDVI, mL/m^2), and ejection fraction. Of the five trauma patients with SACS, the mean age was 36 ± 17, four (80%) male with an Injury Severity Score of 27 ± 9. Pre- and post-LAF, IAP was 20.6 ± 4.7 and 10.6 ± 2.7 ($P < 0.0001$), APP 55.2 ± 5.5 and 77.6 ± 7.1 ($P < 0.0001$), RVEDVI 86.4 ± 9.3 and 123.6 ± 11.9 ($P < 0.0001$), and EF 27.6 ± 4.2 and 40.8 ± 5 ($P < 0.0001$), respectively. One patient needed full decompression for bile ascites from unrecognized liver injury. Linea alba fasciotomy, as a first-line intervention before committing to full abdominal decompression in patients with SACS trauma, improved physiological variables without mortality. Consideration for LAF as a bridge before full abdominal decompression needs further evaluation in patients with polytrauma SACS.

ABDOMINAL COMPARTMENT SYNDROME (ACS) is a condition in which intra-abdominal pressure (IAP) elevates into a state of intraabdominal hypertension (IAH). According to the consensus definitions published by the World Society on Abdominal Compartment Syndrome,[1] IAH is defined as a sustained increase in IAP equal to or above 12 mmHg, whereas ACS is defined as a sustained increase in IAP above 20 mmHg with new-onset organ failure.[2] It is commonly associated with abdominal or pelvic trauma, an intra-abdominal hemorrhagic event, or abdominal surgery.[2–5] If untreated, ACS is often fatal with end-organ dysfunction including impairment of renal and hepatic blood flow, decreased cardiac and pulmonary function, and mesenteric ischemia resulting from rising IAP and subsequent hemodynamic instability.[4, 6–10] These events lead to an increase in intrathoracic pressure (ITP) and thus affect many critical hemostatic processes—decreasing venous and lymphatic return, decreased cardiac output, increased afterload—which can exacerbate the patient's edema and lead to organ dysfunction.[11–13]

Secondary ACS (SACS) is a phenomenon seen in trauma patients without primary abdominal injury after acute resuscitation using crystalloids or blood products, which can subsequently lead to intra-abdominal organ ischemia, edema, and ascites.[14–16] The underlying mechanism is thought to be the outcome of ischemia–reperfusion injury.[3, 4] SACS is seen in patients with shock and increased tissue permeability and often follows the infusion of excessively large volumes of balanced electrolyte solutions or blood products.[11, 17–19]

Open abdominal decompressive laparotomy is the established treatment for refractory SACS; however, this procedure carries many obvious risks associated with an open abdomen, including bleeding, abscess and fistula formation, and malnutrition.[20–22] Leppäniemi et al. proposed subcutaneous anterior abdominal fasciotomy (SAAF) as a treatment for SACS in patients with severe acute pancreatitis. This intervention provided relief of IAH associated with the inflammatory processes and

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fluid resuscitation administered.[23] Their approach was based on a porcine model of ACS, which demonstrated a successful decrease in IAP after a subcutaneous endoscopic abdominal fasciotomy and increased mesenteric blood flow was achieved.[23]

This pilot study was designed to delineate the benefits of this approach in blunt polytrauma patients with SACS. Similar to SAAF, linea alba fasciotomy (LAF) could serve as a bridge intervention of SACS before committing to full abdominal decompression without the complications of an open abdomen.

Methods

This was a 6-month observational pilot study conducted at an urban Level I trauma center. Blunt polytrauma patients with volumetric pulmonary artery catheters (PACs) paced and who developed SACS were included. SACS was defined as ACS that does not originate from direct injury within the abdominopelvic region with IAP greater than 20 mmHg and evidence of organ dysfunction or ischemia.[2–4] Variables measured included patient age, gender, Injury Severity Score, initial base deficit, initial systolic blood pressure (mmHg), volume of packed red blood cells (PRBCs) and crystalloids infused over initial 24 hours, IAP (mmHg), abdominal perfusion pressure (APP, mmHg), right ventricular end diastolic volume index (RVEDVI, mL/m^2), and ejection fraction percentage. Ejection fraction percentage and RVEDVI were measured with volumetric PAC before and after LAF.

IAP was measured through a urinary bladder catheter in a continuous fashion.[24, 25] Patients had a three-way catheter placed, size 18 Fr (Lubri-Sil™ All-Sili-cone Foley catheter; C.R. Bard, Inc., Covington, GA). The continuous IAP measurements were performed through the irrigation port of the three-way catheter, in which continuous normal saline infusion (4 mL/hr) was maintained and connected through a two-way stopcock. Normal saline-filled tubing to a pressure transducer was placed in line with the ileac crest at the midaxillary line and zeroed. Continuous IAP measurement was recorded on the bedside monitor, and APP was calculated continuously by subtracting IAP from mean arterial pressure.

LAF was performed instead of full abdominal decompression to relieve the SACS (Fig. 1). All procedures were performed at the patient bedside under general anesthesia and complete muscle relaxation. Midazolam, fentanyl, and rocuronium were used by anesthesia personnel during the procedures. Using electrocautery, a soft tissue incision was made from xiphoid to pubis. Under direct inspection, in all patients, the linea alba was divided using a scalpel and

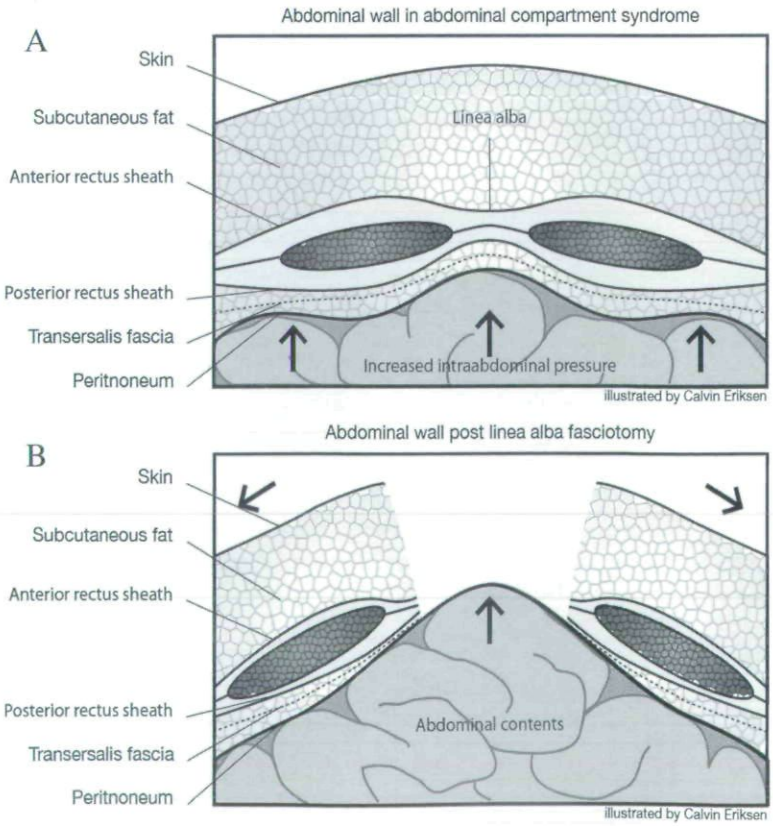

FIG. 1. Schematic representation of pre- (*A*) and post-(*B*) linea alba fasciotomy (LAF) in patients with secondary abdominal compartment syndrome (SACS).

scissors leaving the peritoneum intact. IAP, APP, and volumetric PAC measurements were recorded before and after full LAF. Patients were managed with KCI® (San Antonio, TX) wound-VAC® system placement. Peritoneal washouts were done every other day at the bedside until closure of fascia and skin.

Physiological variables and volumetric information before and after LAF were charted and compared. Statistical analysis was performed using two-sample paired Student *t* test. Changes in physiological parameters are presented as numbers and SDs. A *P* value of < 0.05 was considered significant. Statistical analysis was performed using SAS 9.1.3 (Cary, NC) and SUDAAN 9.0 (RTI International, Research Triangle Park, NC).

Results

A total of five patients (four males and one female) met the inclusion criteria and were enrolled in the study; all had sustained blunt polytraumatic injuries with subsequent development of SACS. All patients were medically managed with sedation, pain control, and paralytics as continuous drips. Mean age, in years, was 36 ± 17 with mean Injury Severity Score of 29 ± 9. Initial systolic blood pressure was 103 ± 32.5 mmHg with a mean base deficit of -9.2 ± 5.5. During the initial 24 hours after trauma, patients received 11.2 ± 3 L of crystalloid solution and 9 ± 8 units of PRBCs.

Pre- and post-LAF measurements, respectively, were as follows: IAP of 20.6 ± 4.7 and 10.6 ± 2.7 mmHg ($P < 0.006$); APP of 55.2 ± 5.5 and 77.6 ± 7.1 mmHg ($P < 0.001$); RVEDVI of 86.4 ± 9.3 and 123.6 ± 11.9 mL/m^2 ($P < 0.001$); and ejection fraction percentage of 27.6 ± 4.2 and 40.8 ± 5.0 ($P < 0.003$) (Fig. 2).

One patient failed LAF as a result of missed liver injury with subsequent development of bile ascites. This patient underwent full abdominal decompression with wide drainage of the liver bed and subsequent abdominal closure without complications. There was no LAF-related mortality in the study group.

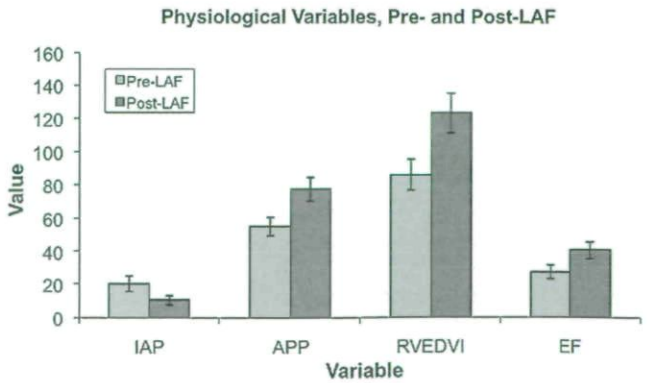

FIG. 2. Physiological and volumetric pulmonary artery catheter (PAC) measurements before linea alba fasciotomy (LAF) and after LAF.

Discussion

Elevated IAP has serious and deleterious effects on a patient's morbidity and mortality, affecting nearly every major organ system. This pilot study shows promise for the use of LAF as a bridge intervention of SACS after failure of maximal medical management before committing to full abdominal decompression. Physiological data obtained from patients both before and after LAF clearly demonstrate an improvement of four main variables: IAP, APP, RVEDVI, and ejection fraction. Overall, a decrease was noted in IAP, increases were noted in APP and ejection fraction, and a marked increase was observed in RVEDVI.

The current study shows an approximate mean increase of 22 mmHg in APP after LAF. By performing LAF, the resistance placed on the compliance of the abdominal wall is reduced by reducing the delta tension of the abdominal muscles within their fascial restraints. This allows the abdomen, specifically the peritoneum, to expand further than when the abdominal muscles are intact and thus allows for the reduction of IAP. This intervention results in a reduction in IAP with improvement in APP and mesenteric perfusion.

Increased IAP has profound effects on the cardiovascular system in many different ways. IAH can increase the pressure placed on the diaphragm, thus rising ITP. The compliance of the thorax is somewhat limited by the compliance of the chest wall and thus rising ITP has the same effect on the large thoracic vessels and heart as rising IAP has on the vasculature in the abdomen.[5]

Cardiac function is comprised of three major components, all of which are impaired in cases of rising ITP: preload, contractility, and afterload.[6] Preload and afterload are both addressed in this study. Decreased preload yields decreased RVEDVI, thus reducing cardiac output and stroke volume. Increased pressure on the inferior vena cava (IVC) is thought to be a major component in patients with IAH.[26] This increased pressure on the IVC will lead to a decreased volume of blood returned to the right atrium and thus a reduced amount of blood that is available for pumping from the heart. Increased upward deviation of the diaphragm can also cause decreased preload by mechanically narrowing the IVC and thus decreases its capacity to return blood to the heart.[6]

Hypovolemic patients have been shown to manifest reduced cardiac outputs at lower IAP levels than normovolemic patients. In a study by Kashtan et al., at an IAP of 40 mmHg, hypovolemic dogs had a 53 per cent

reduction in cardiac output compared with a 17 per cent reduction in normovolemic dogs.[27] Coupling both the hypovolemic nature of many polytrauma patients with an elevated ITP secondary to rising IAP, cardiac output, and stroke volume can be negatively affected. The current study demonstrated a mean increase in RVEDVI of 37.2 mL/m^2 after LAF. By reducing the IAP through LAF, ITP was reduced with an increase in preload from the IVC. This allows for a higher volume of blood to be returned to the right atrium and, likewise, an increase in the end-diastolic volume of the right ventricle. This increase in preload allows for better perfusion of the lungs and a larger RVEDVI.

Also demonstrated in the current study was an increase of 13.2 per cent in ejection fraction after LAF. Similar to the compressive effect on the IVC by elevated ITP, increased ITP can compress the aorta and systemic vasculature, raising systemic vascular resistance (SVR). Pressure on the aorta as well as vascular resistance as a property of the aorta provides a higher pressure against which the heart must pump against, creating increased afterload and thus reducing the ejection fraction.[6] The reduction in IAP resulting from LAF in turn reduces ITP with an increase in venous return (preload) and a decrease in SVR (afterload). This allows for a higher ejection fraction to be expelled from the left ventricle and into systemic circulation.

The incidence of developing SACS is multifactorial and not strictly the result of massive crystalloid fluid resuscitation after trauma or ascites development; many studies have also shown development of SACS after burn injury.[4, 28] In a recent study by Leppäniemi et al., ACS was examined in relationship to severe acute pancreatitis with various surgical and nonsurgical treatments discussed. The subcutaneous LAF approach was first described.[23] This intervention showed promise in decreasing IAP with the benefits of avoiding the morbidity seen with full abdominal decompression.[29, 30] Reducing morbidity is crucial because many surgeries or injuries that result in ACS have an inherent high risk of morbidity themselves.[31]

This study proposes the use of LAF as a bridge intervention to full abdominal decompression in patients with known SACS who have failed medical management. SACS is secondary to capillary leak, edema, and ascites from an injury outside of the abdomen.[3, 4] In the current study, one patient had a missed liver injury with bile ascites discovered 2 days after LAF. Once the liver injury was discovered after LAF, full abdominal decompression was performed to ensure the patient's safety and to properly assess and manage the liver injury. If surgical treatment is required for patients with primary ACS, a full laparotomy should be the treatment option. Thus, LAF should not be considered in the primary ACS patient population and should only be implemented as first-line surgical treatment in patients with SACS with no intra-abdominal pathology.

Conclusion

Although the focus of this pilot study was directed toward polytrauma patients, the importance of refining surgical management of ACS applies to most, if not all, medical specialties. Appropriate monitoring and treatment measures must be implemented to adequately prevent and respond to development of SACS. This pilot study is a critical step in refining the accepted surgical treatment of SACS. Although additional research is needed to refine these measures and techniques, the data presented here offer evidence that LAF provides promising relief of elevated IAP without the increased morbidity and mortality of full abdominal decompression. LAF should be taken into consideration as first-line surgical treatment in patients with SACS.

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