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A clinical study

NTNU
Norwegian University of Science and Technology

Thesis for the Degree of Philosophiae Doctor

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Contents

NORSK SAMMENDRAG

Formålet med dette doktorgradsarbeidet var å bedre behandlingen for pasienter med åpen buk. Åpen buk betyr at kirurgen enten lar være å lukke såret etter en operasjon i bukhulen, eller har måttet åpne bukveggen ved en senere anledning. Dette for å forebygge eller behandle bl.a. abdominalt kompartmentsyndrom. Dette syndromet kan oppstå etter store kirurgiske inngrep som operasjon for sprukket hovedpulsåre, ved tarmslyng med perforasjon av tarm og bukhinnebetennelse, ved behandling for blodforgiftning og ved behandling av alvorlig skadede pasienter. Abdominalt kompartmentsyndrom oppstår når livsnødvendig tilført intravenøs væske lekker ut fra blodbanen og fører til hevelse i bukorganene. Bukveggen er lite ettergivelig og en hurtig økning i volum av bukorganene medfører at trykket i bukhulen stiger og blodtilførselen til bukorganene reduseres med påfølgende organsvikt og utvikling av abdominalt kompartmentsyndrom. Dette er en meget alvorlig tilstand som har høy dødelighet til tross for avansert kirurgi og intensivbehandling. Monstrøse arrbrokk er vanlig hos de som overlever.

Den første artikkelen i denne avhandlingen evaluerte en ny metode for behandling av pasienter med åpen buk etter operasjon for utposning av hovedpulsåren; vacuum assisted wound closure with mesh mediated traction, VAWCM, samt rutiner og prosedyrer for å oppdage og behandle abdominalt kompartmentsyndrom. Metoden gir bedre plassforhold i bukhulen og forebygger utviklingen av monstrøse brokk. I denne studien ble organsvikt reversert ved å legge bukhulen åpen, og åtte av ni pasienter overlevde behandlingen med åpen buk. To døde senere under sykehusoppholdet. Hos alle pasientene kunne bukveggen lukkes gradvis og metoden forebygde store arrbrokk.

I artikkel to presenterte vi en egenutviklet teknikk, Chimney-VAC, for å behandle lekkasje fra tarm hos pasienter med åpen buk, såkalt enteroatmosfærisk fistel. Tarmlekkasje er en meget alvorlig komplikasjon ledsaget av høy dødelighet. Den friske delen av tarmen ble dekket med en vevsvennlig svamp, med en åpning som ble plassert over tarmlekkasjen. En skorstein ble så konstruert av samme type hvit svamp og plassert over åpningen. Et nett, med åpning til skorsteinen ble så sydd fast i bukveggen og så dekket med svamp. Negativt trykk ble applisert

over skorsteinen og regelmessige skiftninger og stramninger av nettet førte til at buksåret kunne lukkes og en kontrollert stomi ble etablert.

Pasienter med åpen buk har behov for repeterte operasjoner for å få lukket bukveggen. I artikkel tre analyserte vi det å utføre planlagte prosedyrer for sårskift av åpen buk på intensivavdelingen i stedet for på operasjonsstuen. Vi fant ut at vi sparte over 30 minutter for operasjonsteamet og nesten to timer for anestesiteamet pr. sårskift ved å utføre prosedyren på intensivavdelingen. Dette medførte en besparelse på over 6000 NOK pr. operasjon for sykehuset. Sårskift for åpen buk ved intensivavdelingen medførte ingen økning i dødelighet eller forekomst av positive blodkulturer. Praksisen med å utføre operasjoner på intensivavdelingen var besparende for sykehuset og trygg for pasienten.

I studie fire, som er en retrospektiv studie av alle 118 pasienter som er blitt behandlet med åpen buk ved St. Olavs Hospital fra 2006 til 2014, analyserte vi årsakene til å benytte åpen buk som behandling. Vi fant at over halvparten ble behandlet, eller fikk en forebyggende behandling av abdominalt kompartmentsyndrom. Alle pasientene ble behandlet med vakuumbandasje, de aller fleste med VAWCM. I gjennomsnitt tok det tolv dager før bukveggen kunne lukkes og pasientene lå 29 dager på sykehuset, hvorav 15 dager på intensivavdeling. Flesteparten fikk lukket buksåret primært, og kun 2 % endte med et monstrøst brokk. Nær 70 % overlevde behandlingen. Høy alder, abdominalt kompartmentsyndrom og behov for dialyse medførte økt dødelighet. Alle ni pasienter med enteroatmosfærisk fistel overlevde. Studien viste at pasientene fikk svært avansert behandling, og at flesteparten overlevde.

Delstudiene i denne avhandlingen vurderte innføring av nye teknikker for behandling av åpen buk og som bedret utfallet for denne krevende pasientgruppen. Dette kan endre sykehusenes rutiner for behandling av åpen buk. Flere studier, helst prospektivt kontrollerte og med deltakelse fra flere sykehus, er nødvendig for å evaluere om metodene er generaliserbare til de fleste sykehus og kompetansemiljøer.

ACKNOWLEDGEMENTS

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I want to thank colleague Lars Cato Rekstad for his enthusiasm, good discussions and his talent to see alternative methods for improving patient care. Further I want to thank my co-workers and colleges from Department of Surgery and Department of Anesthesiology and Intensive Care Medicine, a specially thank to Professor Pål Klepstad for fast, constructive and well formulated reviews of manuscripts.

Also a big hand to the nurses in the operating room and intensive care unit for their patient and support to this project, and the residents at the Surgical Clinic for their tremendous job with performing the dressing changes.

Thanks to my two mentors in surgery, Tore Gauperaa and Brynjulf Ystgaard.

Thank to my children, Ella, Herman and Frida for supporting and keeping out with a grumpy old father with a desire to become a scientist in his old ages and thank to my wife Asta for keeping up the speed and pace in this work, “A day without writing is a day without meaning.”

Thank to my parents, Halldis and Bjarne.

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LIST OF PAPERS

I **Seternes A**, Myhre HO, Dahl T. Early results after treatment of open abdomen after aortic surgery with mesh traction and vacuum-assisted wound closure. *Eur J Vasc Endovasc Surg. 2010; 40: 60-64.* doi: 10.1016/j.ejvs.2010.02.018.

II Rekstad LC, Wasmuth HH, Ystgaard B, Stornes T, **Seternes A**. Topical negative-pressure therapy for small bowel leakage in a frozen abdomen: A technical report. *J Trauma Acute Care Surg. 2013 Sep; 75(3):487-91.* doi: 10.1097/TA.0b013e3182995e6d.

III **Seternes A**, Fasting S, Klepstad P, Mo S, Dahl T, Björck M, Wibe A. Bedside dressing changes for open abdomen in the intensive care unit is safe and time and staff efficient. *Crit Care. 2016 May 28; 20(1):164.* doi: 10.1186/s13054-016-1337-y.

IV **Seternes A**, Rekstad LC, Mo S, Klepstad P, Halvorsen DL, Dahl T, Björck M, Wibe A. Open Abdomen Treated with Negative Pressure Wound Therapy: Indications, Management and Survival. *World J Surg. 2017 Jan;41(1):152-161.* doi: 10.1007/s00268-016-3694-8.

LIST OF ACRONYMS AND ABBREVIATIONS

CVVHDF	Continuous venovenous hemodiafiltration
AAA	Abdominal aortic aneurysm
ACS	Abdominal compartment syndrome
APP	Abdominal perfusion pressure
BSI	Bloodstream infection
DL	Decompressive laparotomy
EAF	Entero-atmospheric fistula
EPR	Electronic Patient Record
IAH	Intra-abdominal hypertension
IAP	Intra-abdominal pressure
ICP	Intra-cranial pressure
ICU	Intensive care unit
LOS	Length of stay
MAP	Mean arterial pressure
MOF	Multi-organ failure
NPWT	Negative pressure wound therapy
OA	Open abdomen
OR	Operating room
PAS	Patient administrative system
RALP	Robotic-assisted laparoscopic prostatectomy
RRT	Renal replacement therapy
SAPS II	Simplified Acute Physiology Score II
SOFA-score	Sequential Organ Failure Assessment score
SvO_2	Mixed venous oxygen saturation
TAC	Temporary abdominal closure
VAWC	Vacuum-assisted wound closure
VAWCM	Vacuum-assisted wound closure with mesh-mediated fascial traction
WSACS	The Abdominal Compartment Society , earlier called The World Society of the Abdominal Compartment Syndrome

ENGLISH SUMMARY

The aim of this thesis was to improve open abdomen treatment. Open abdomen (OA) is the situation when the surgeon avoids closing the laparotomy, or has to open the abdominal incision later on due to treatment or prevention of abdominal compartment syndrome (ACS) or diseases in the abdominal wall. ACS is seen after major surgery for ruptured abdominal aortic aneurysm, peritonitis, pancreatitis, intestinal obstruction, after treatment for major trauma, and sepsis. Development of ACS is due to leakage of fluids out of the bloodstream, during and after resuscitation, followed by edema in intraabdominal organs. This is accompanied by an increased intra-abdominal pressure (IAP) further reducing blood flow into vital organs with subsequent dysfunction. The diagnosis is based on IAP>20 mm Hg and a new developed organ failure. Although early recognition and treatment, ACS is deadly despite advanced surgery and intensive care treatment. Survival after OA is often accompanied with a giant incisional hernia with only a split skin graft covering the intestines.

In paper I early experiences with a new treatment of OA after aortic repair was presented; vacuum assisted wound closure with mesh mediated traction, VAWCM, a method developed to prevent giant hernia after OA. VAWCM enables both treatment of ACS and prevention of giant hernia through a combination of traction to the rectus fascia with a temporary mesh and to establish negative pressure wound therapy (NPWT). In this study treatment reversed organ failures and eight out of nine patients survived until closure of the OA, but two patients died later on. The OA could be closed after a median of 10.5 days and four dressing changes. Follow-up detected two small incisional hernias. The treatment prevented giant hernia formation.

In paper II we presented our own invented method, Chimney-VAC, for treatment of entero-atmospheric fistulas (EAF) in OA patients. Intestinal leakage is a feared complication OA, accompanied by a significant mortality rate. In this method, white foam was used to cover the reinforced, was then placed on top of the opening of the white foam. If not already in place, a polypropylene mesh was sutured to the fascial edges to mediate traction, and then covered with black foam. The VAC-therapy was then connected and the connector was placed on top of

the chimney, draining both the fistula and the OA, preventing intestinal fluid to leak into the OA. After repeated dressing changes with tightening of the mesh the OA could be closed and a controlled entero-cutaneous fistula was established, and the patients could be discharged from the hospital.

Patients with OA are in need of repeated visits to the operating room for surgical procedures. In study III we compared using the ICU and the OR for dressing changes for OA. Utilizing the ICU saved more than 3o minutes for the surgical team and almost two hours for the anesthesia team, and the saved personnel costs were 682€ per dressing change. The in-hospital survival and the rates of blood stream infections were not influenced on where the dressing changes took place. Performing the dressing change at the ICU seemed to be safe regarding in-hospital survival and rates of blood stream infections, and it saved money for the hospital.

In study IV, an evaluation of all 118 consecutive patients treated with OA at St. Olavs Hospital between October 2006 and June 2014, more than 50% received OA in the purpose to treat or to prevent ACS. All patients were treated with NPWT, most of them with VAWCM. Patients were treated with OA at a median of twelve days, and they stayed at a median of 29 days at the hospital, including 15 days at the ICU. In total, 68% survived until discharge, and per-protocol delayed primary fascial closure was achieved in 84% of the patients. Only 14% were in need of more advanced reconstruction and only two per cent ended with a giant hernia. Five of the nine patients treated for EAF received treatment with Chimney-VAC, and all patients with EAF survived. Advanced age, ACS and renal replacement therapy were independent predictors for death. In conclusion, 118 patients with OA received advanced treatment, and most of them survived without a giant hernia

The studies in this thesis evaluated implementation of new surgical treatments for OA which might change the way the hospitals have to deal with this high resource dependent group of patients. The VAWCM technique has almost eliminated the occurrence of giant hernia after OA, and the Chimney-VAC is a promising method to deal with EAF.

INTRODUCTION

Intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS)

The abdominal cavity is limited by the abdominal wall, the spine, the diaphragm and the pelvis, and it contains major organs such as the liver, kidneys, pancreas, stomach, small and large intestine, adrenal glands and large blood vessels viz. the abdominal aorta and the inferior vena cava. The pressure in the abdominal cavity, the so-called intra-abdominal pressure (IAP), is normally below 10 mmHg, but it will vary physiologically with the body position and can also adapt over time to an increased pressure for instance with increasing body weight or BMI [1-3]. Intra-abdominal hypertension (IAH) is defined as sustained or repeated measurements of IAP>12mmHg and is graded from 1 to 4 [3] (Table 1). Abdominal compartment syndrome (ACS) is increased IAP with an organ failure/dysfunction, defined in the guidelines from The World Society of the Abdominal Compartment Syndrome (WSACS) [3] (Table 2). Organ failure is evaluated on a daily basis by the Sequential Organ Failure Assessment (SOFA) score (Table 3) and scores of 3 and 4 are defined as organ dysfunction/failure [4].

Table 1: Definition of Intra-abdominal hypertension (IAH)

Grade 1	IAP 12-15mmHg
Grade 2	IAP 16-20mmHg
Grade 3	IAP 21-25mmHg
Grade 4	IAP>25mmHg

IAP, Intra-abdominal pressure.*Adapted from WSACS guidelines. Malbrain ML, Cheatham ML, Kirkpatrick A*, et al.* Results from the International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome. I. Definitions Intensive Care Med 2006: 32; 1722-1732

Table 2: Definition of abdominal compartment syndrome (ACS)

Sustained intra-abdominal pressure (IAP)>20mmHg (with or without an abdominal perfusion pressure (APP) <60mmHg) that is associated with a new organ dysfunction/failure.

Adapted from WSACS guidelines. Malbrain ML, Cheatham ML, Kirkpatrick A, et al.* Results from the International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome. I. Definitions Intensive Care Med 2006: 32; 1722-1732 [3].

Table 3: Sequential organ failure assessment score (SOFA score)

	SOFA score			
	1	2	3	4
Respiration PaO2/FiO2,	<400	<300	<200	<100
			With respiratory support	
Coagulation Platelets x $10^3/mm^3$	<150	<100	<50	<20
Liver Bilirubin µmol/l	20-32	33-101	102-204	>204
Cardiovascular Hypotension	MAP<70 mmHg	Dopamin≤5µg/kg/min or Dobutamine in any dose	Dopamin>5µg/kg/min, or A≤0.1µg/kg/min, or NA≤0.1µg/kg/min	Dopamin>15µg/kg/min, or A>0.1µg/kg/min, or NA>0.1µg/kg/min
CNS Glasgow Coma Scale	13-14	10-12	6-9	<6
Renal Creatinin µmol/l or urine output	110-170	171-299	300-440, or <500 ml/day	>440, or <200 ml/day

PaO2/FiO2, Ratio of arterial oxygen tension to fraction of inspired oxygen A, Adrenaline. NA, Noradrenaline. CNS. Central nervous system. Adapted from Vincent JL, Moreno R, Takala J*, et al.* The SOFA (Sepsis-related Organ Failure Assessment) score to describe organ dysfunction/failure. On behalf of the Working Group on Sepsis-Related Problems of the European Society of Intensive Care Medicine Intensive Care Med 1996: 22; 707-710

Diagnosis of IAH and ACS

A tense abdomen with distension should raise the suspicion of increased IAP, and followed by a more accurate measurement by either direct or indirect methods. A clinical evaluation is not sufficient [5]. IAP can be evaluated directly in the abdominal cavity, or indirectly via rectum, stomach or urinary bladder, in an intermittent or continuous fashion [6]. The preferred technique is the indirect method through the urinary bladder. The Foley Manometry method is easy to perform and reproducible in a clinical setting with good correlation to the gold standard[6, 7]. The preferred measurement unit is mmHg. The patient should be in the supine position and relaxed. Furthermore, repeated measurements should be done at end-expiration with the pubic symphysis as the zero-level[8] in order for the Foley Manometry method to be valid.

Etiology of IAH and ACS

The observation of an elevated IAP and the effect of decompression after aortic surgery were first published by Kron et.al in 1984 (Kron, Harman et al. 1984), and termed ACS by Fietsam et al. in 1989 [7, 9]. Since then, multiple studies have reported development and treatment of IAH and ACS. The raised IAP may be explained by stiffness of the abdominal wall as seen in serious burns, by increased intra-luminal content as seen in ileus, hemorrhage, capillary leakage due to sepsis and multi-trauma management, or by increased intraabdominal content as seen in patients with pancreatitis. Often there will be a combination, as in several burns with need of fluid resuscitation and a burned torso with restricted compliance to adopt the increased fluid volume resulting in an increased IAP. In patients treated for ruptured abdominal aortic aneurysm having an increased abdominal content due to the presence of a retroperitoneal hematoma combined with massive fluid replacement prior to, during and after surgery, there is a considerable risk of ACS [8, 10]. See Table 4 for an overview of the most common medical risk factors for IAH and ACS. Development of IAH and ACS should be suspected in all critical ill patients with capillary leakage, need of poly-transfusion and massive fluid resuscitation, with

coagulopathy and/or acidosis with concomitant development of organ dysfunction(s) [3, 8]. Moreover, excessive fluid resuscitation with crystalloids in patients surviving damage control surgery can lead to a second hit of organ failure when patients are treated in the intensive care unit (ICU) after initial surgery [11]. This is now a well-recognized complication, and modern fluid resuscitation consists of packed red blood cells, fresh frozen plasma and platelets with limited used of crystalloids to avoid IAH and ACS after initial surgery [11, 12].

Table 4: Risk factors for intra-abdominal hypertension and abdominal compartment syndrome

Diminished abdominal wall compliance
Abdominal surgery, major trauma, major burns, prone positioning
Increased intra-luminal contents
Gastroparesis/gastric distension, ileus, colonic pseudo-obstruction, volvulus
Capillary leak/fluid resuscitation
Acidosis, damage control laparotomy, hypothermia, increased SOFA or APACHE-II score, massive fluid resuscitation, polytransfusion
Increased intra-abdominal contents
Acute pancreatitis, distended abdomen, hemoperitoneum, pneumoperitoneum, abscess/infection, tumors, fluid collections, liver failure with ascites, peritoneal dialysis
Other
Age, bacteremia, coagulopathy, massive incisional hernia repair, mechanical ventilation, BMI>30, PEEP>10, sepsis and pneumonia, hypotension

SOFA, sequential organ failure assessment. APACHE-II, acute physiology and chronic health evaluation-II. BMI, body mass index. PEEP, positive end expiratory pressure. Adapted from Kirkpatrick AW, Roberts DJ, De Waele J*, et al.* Intra-abdominal hypertension and the abdominal compartment syndrome: updated consensus definitions and clinical practice guidelines from the World Society of the Abdominal Compartment Syndrome Intensive Care Med 2013: 39; 1190-1206

Consequences of ACS

An increased IAP results in reduced blood flow in the intra-abdominal organs such as the kidneys, liver, stomach, small intestine, colon and pancreas [13-15]. In the kidneys, the glomerular filtration rate decreases and the vascular resistance increases resulting in renal dysfunction [16]. For the liver, the increased IAP results in reduced portal venous blood flow

and arterial hepatic blood flow [17, 18]. Data suggest that the increased IAP contributes to ischemia in the gut with bacterial translocation and subsequent multi-organ failure [19-21]. An increased IAP can also significantly influence extra-abdominal organs such as the heart and lungs because of reduced venous return due to compression of the inferior vena cava, renal and mesenteric veins. In addition, systemic vascular resistance in the abdomen and lungs increases after-load. The lungs are also affected by anatomical restrictions when the abdominal content increases in volume. This leads to elevation of the diaphragm, reduced thoracic volume and respiratory failure. Increased intra-thoracic pressure in turn reduces right ventricular end diastolic volume [22]. There is also a connection between the IAP and the intra-cranial pressure (ICP), mainly caused by obstruction of the cerebral venous outflow/return due to increased intra-thoracic pressure and also increased pressure on the venous plexuses in the lumbar region [14, 23, 24].

Primary, secondary and recurrent ACS

ACS can be differentiated into three types. Primary ACS may be observed in patients after surgery for intra-abdominal diseases such as ruptured and intact abdominal aortic aneurysm, abdominal trauma, acute pancreatitis, peritonitis, and intra-abdominal and retroperitoneal bleedings [3]. Secondary ACS may develop in patients treated for conditions outside the abdominal cavity such as sepsis, burns, or conditions in need of massive fluid resuscitation [3, 25]. The third type is recurrent ACS, a condition seen in patients initially treated for ACS earlier in the course of their illness and who experience a new increase in the IAP with a new organ failure and the need for an another surgical decompression. The incidence of ACS is dependent on the population at risk. After aortic surgery reported figures vary from 1-30% [10, 26-28], in trauma patients 1-14% [25, 29] and 4-23% in patients in a mixed surgical intensive care unit [30, 31].

Treatment of IAH and ACS

If possible, the best way to deal with ACS is to prevent it [32]. It is essential to systematically identify patients at risk; such as critically ill patients with poly-transfusions and mass-transfusion following sepsis, peritonitis, major trauma, major abdominal surgery, burns etc.(Table 4)[3]. It is also essential to perform systematic measurements of the IAP in patients at risk and initiate treatment for IAH before ACS develops. For patients in the ICU with IAP ≥ 12mmHg, the algorithm from WSACS should be followed with IAP measurement every four to six hours, if possible evacuation of intraluminal contents, percutaneous drainage of intra-abdominal lesions, improving abdominal wall compliance, adequate pain management considering neuromuscular blockade, and optimizing fluid administration and improving systemic and regional perfusion[3, 8, 33-35]. For some patients, there is also the option to not close the abdominal wound after major acute surgery to prevent ACS, leaving the patients with an open abdomen (OA) [36, 37]. Other indications for leaving the patient with an OA are abdominal sepsis with the need of repeated wash outs, necrotizing fasciitis of the abdominal wall with repeated resection of the abdominal wall and damage control laparotomy in trauma care[37]. If a patient presents with overt ACS, it is inappropriate to wait for conservative treatment, as outlined above. Surgical decompression of the abdominal cavity is necessary to reduce IAP with a following improvement of organ dysfunctions due to increase in cardiac output and reduction of the end-expiratory pressure requirement [33, 38, 39]. The established way to perform the surgical decompression is through a mid-line laparotomy, but a less invasive alternative with a subcutaneous fasciotomy is also an option [40]. Despite optimal care in the ICU and surgical decompression, the morbidity and mortality is still significant for patients treated with OA, especially when treated for ACS [30, 38, 39].

Open abdomen (OA)

An OA will need a temporary abdominal closure (TAC) to cover and protect the intra-abdominal content, and to prevent hypothermia and fluid loss. Several solutions are available from the simple Bogota bag (Fig.1) consisting of a plastic bag sutured to the skin or fascia to cover the abdominal content[41]. This is a simple and cheap bail out method when closing the laparotomy is not possible or appropriate. The method is challenging for the ward personnel taking care of the patient due to excessive fluid leakage between the suture line and the skin with the need of repeated bed changes during the day and reduced control of the patient's fluid balance. Repeated changes were done until the intestines were covered with granulation tissue followed by a split skin graft procedure and prolonged recovery. Due to the lack of fascial traction, the abdominal musculature and rectus fascia retracted laterally with insufficient cover and support of the abdominal content, and thus the survivors were left with a giant incisional hernia (Fig.2).

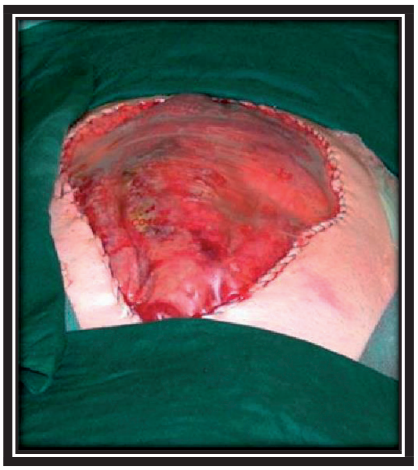

Figure 1: Open abdomen with Bogota bag

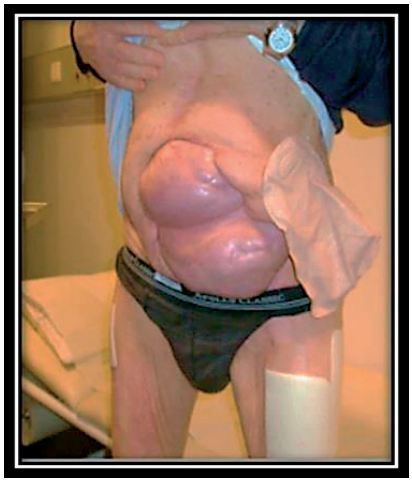

Figure 2: Open abdomen after treatment with Bogota bag and split skin graft

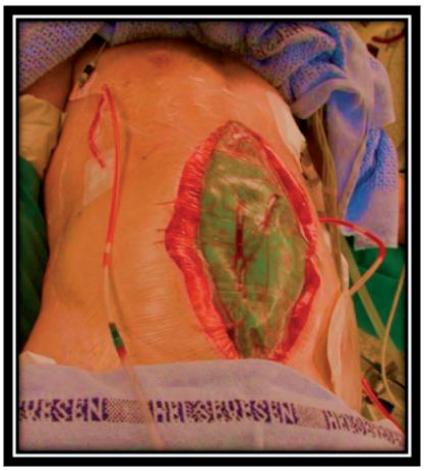

Figure 3: Open abdomen with VAC PAC

To prevent excessive fluid loss and ease the OA treatment, the vacuum pack method (VAC-PAC) was developed, introducing negative pressure wound therapy when dealing with patients with OA [42](Fig.3). To avoid fascial retraction and giant incisional hernias following OA, several methods were developed to maintain traction to the fascial edges during a staged closure of the OA with the use of mesh, zippers, sutures and Velcro-meshes [43-45]. To avoid both fascial retraction and uncontrolled fluid loss, several methods using a combination of NPWT and fascial traction were developed to best deal with the acute treatment and preventing a giant hernia with the need of extensive abdominal wall reconstruction afterwards [46-48]. In the consensus guidelines for IAH and ACS treatment published in 2007 for patients in need of more than five to seven days with OA, primary fascial closure can be difficult and closing with split-skin graft or skin flaps may be necessary with a giant hernia as a result [8]. The same year, Petersson et al. introduced a new method for TAC combining NPWT and traction of the rectus fascia with a temporary mesh, the Vacuum-assisted wound closure and mesh-mediated fascial traction, VAWCM[49](Figs.4 and 5).

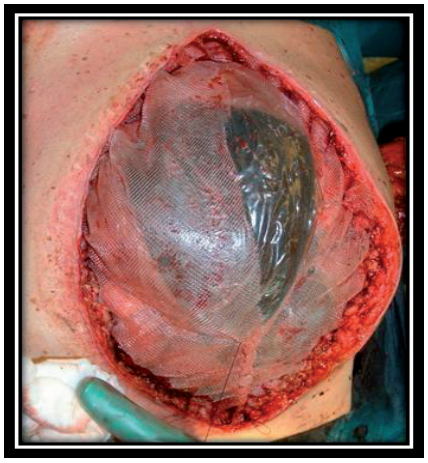

Figure 4: NPWT with mesh in place, VAWCM

In that study seven patients were treated with VAWCM and delayed fascial closure could be achieved in all patients after 12 to 52 days. Despite more than five to seven days with OA there was no need for planned incisional hernia, thus representing a small revolution for OA treatment (Fig.6).

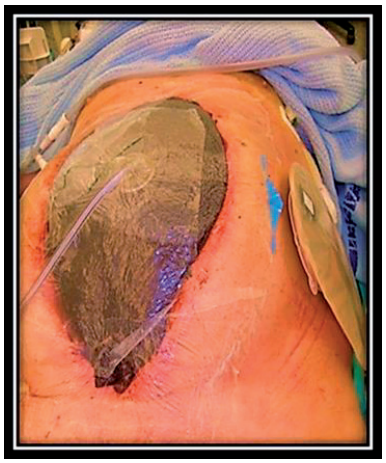

Figure 5: Sponge and vacuum covering the mesh, VAWCM

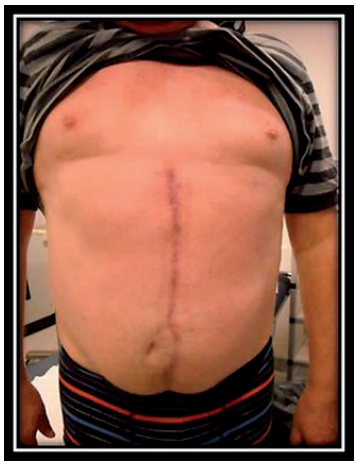

Figure 6: Open abdomen after treatment with VAWCM

Enteric leak and entero-atmospheric fistula (EAF)

Recent research has shown that there is a considerable gradient across the abdomen with regard to the negative pressure applied at the surface of the foam. Despite a large negative pressure at the surface (125 mmHg), the negative pressure on the intestine is low and mostly independent of the negative pressure set to the pump [50]. In line with these physiological observations, a prospective study from Great Britain including almost 600 patients found less gastrointestinal fistulas in patients having NPWT for OA than in those treated without [51]. The initial hypothesis that NPWT caused EAF has thus been disproven, still enteric leak and EAF are feared complications in OA. The treatment of choice is early closure of the defect in the intestine, deviation of the intestinal leak through a stoma or an entero-cutaneous fistula. If it is not possible to externalize the leakage, the patient will end up with an EAF with significant mortality, in one study reported to be even 100 % [51-56]. Open abdomen with an EAF is classified as ≥ Grade 3 OA [57, 58](Table 6). Several methods were developed to take care of this serious complication with the primary goal of preventing intestinal fluid leakage into the open abdomen that will cause and maintain an abdominal sepsis [59, 60].

Organizational issues related to ACS and open abdomen treatment

Treatment of OA patients is demanding, and requires a multidisciplinary approach to obtain the best possible outcome for the patient. OA often requires prolonged care in the ICU with particular attention to organ dysfunctions with mechanical ventilator, inotropic support and renal replacement therapy (RRT). Usually there are several reoperations before discharge, which means repeated intra-hospital transports to and from the operating room for dressing changes and other minor or major surgical procedures [61, 62]. Transport to and from the operating room (OR) might be stressful for both the patient and the staff at the ICU and OR, and carry the risk of adverse events during transport, with difficulties in handling oncoming complications outside the familiar working location [63, 64]. Several studies have reported that both minor and major surgical procedures can be performed outside of the OR [65-73]. Utilizing the ICU

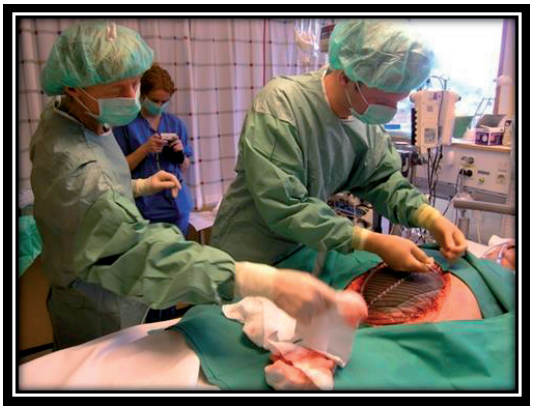

Figure 7: Dressing change in the ICU

Surgery taking place between 8am and 5pm Monday to Friday.

Frame 1: Definition of office hours surgery at St.Olavs Hospital

room as an OR for repeated dressing changes during OA treatment offers an opportunity to reduce the use of the regular OR facilities, patient transportation, personnel and costs. Whether this is safe has not been previously studied. Utilizing the ICU to perform the dressing changes, may result in that more of the changes are performed as planned during office hours [55, 59]. A particular bottleneck is the anesthesia team which serves the entire hospital. Alas, more urgent incoming cases often delay the scheduled OA dressing change, which then has to be performed by surgeons on call, with less experience.

AIMS OF THE THESIS

1. To evaluate a new surgical method for ACS and OA after aortic surgery with emphasis on short time outcomes (Paper I).
2. To develop a surgical method for treatment of EAF in the OA patient (Paper II).
3. To evaluate the patient safety of using the ICU for dressing changes for OA (Paper III).
4. To evaluate if the use of ICU as an OR for dressing changes for OA treatment saves time and personnel costs compared to traditional OR use (Paper III).
5. To identify factors associated with increased mortality for patients with OA based on a consecutive hospital register (Paper IV).
6. To calculate and estimate the resources used in the hospital for treatment of patients with OA (Paper IV).

METHODS

Setting

This was a single center study at St. Olavs University Hospital, a tertiary referral hospital for 720 000 inhabitants in Mid-Norway, and a level I trauma center. The Department of Surgery consists of 83 regular beds and seven high-dependency beds, eleven OR for elective and one OR for 24/7 emergency surgery. The annual workload for Department of Surgery is approximately 8500 surgical procedures. Staff and OR availability for emergency surgery are limited, and shared by several surgical specialties. Thus prioritizing between patients in need of emergency surgery is done by the surgeons on call according to a traffic light system and is classified into red, yellow and green with maximum 6, 24 or 72 hours delay before surgery. The ICU consists of ten beds for mixed cases with intensive care physicians and nurses responsible for the treatment 24/7.

Treatment goals in the ICU for patients with circulation failure is to maintain a MAP >70 mmHg and SvO_2 > 65% with the use of crystalloids, colloids and/or vasoactive drugs. In cases with respiratory failure, the treatment goal is to achieve PaO_2 > 8 kPa and/or $SatO_2$ > 90%. Preferred method for renal replacement therapy in acute renal failure is continuous veno-venous hemodiafiltration (CVVHDF) with 25ml/kg/h inflow. Enteral nutrition is preferred over parenteral nutrition, with 20-35 kcal/kg/24h.

Cohorts - inclusion and exclusion criteria

All consecutive patients treated with OA between October 2006 and June 2014 were included in this thesis. In paper I, the registration was prospective, and the first nine consecutive patients treated with VAWCM were investigated. Paper II was a description of a new technique and consisted of two illustrative patient cases. Paper III included 98 patients with OA treated in the ICU. The effect of location of dressing change, i.e. ICU vs OR was analyzed for 98 patients who were in need of more than one dressing change. Paper IV included all 118 patients treated with

OA. For Papers III and IV, identification of patients and entry of parameters were done retrospectively.

Data sources

Treated patients were identified in the hospital's patient administrative system (PAS) and from the surgical procedure registry with search on relevant codes from the Nomesco Classification of Surgical Procedures; JAH30 (laparostomy), JAH33 (revision of laparostomy) and WLGX20 (Negative pressure wound therapy (NPWT)) and through searches in several local quality and complication registries. For the vascular patients the identification was validated against the NORKAR registry[74]. Clinical data were gathered from electronic patient records (EPR), surgical procedure registry, microbiological registry, ICU-registry and the anesthesia registry [75].

Data collection

Gender was obtained from PAS.

Age was obtained from PAS and measured in whole years.

Length of stay in hospital, LOS total hospital, was measured in days, and data were obtained from PAS. Admission duration between 0-24 hours was set to one day.

Length of ICU stay, LOS ICU, was measured in days, and data were collected from the ICU registry and checked against PAS. Admission duration between 0-24 hours was set to one day.

Duration of OA treatment was measured in number of days, and data were obtained from EPR.Time from initial aortic surgery until OA was reported in number of days and data were obtained from EPR.

Time from initial surgery and reoperation for ACS were measured in hours, and data were obtained from the surgical procedure registry and checked against the anesthesia registry. In the OR registry, data were directly entered into this database by the OR nurse. For the

anesthesia registry, department secretaries entered data from written records until 2011. From 2011 anesthetic nurses entered data directly using electronic anesthesia records.

Length of the preoperative, surgical, post-operative and anesthesia time were obtained from the OR and the anesthesia registries. These data were reported in minutes.

Duration of mechanical ventilation support was measured in days and data obtained from ICU registry. Data entry was accomplished by the physicians at the ICU.

Organ failure was evaluated with SOFA score that was registered once daily, and a score > 3 was defined as organ failure (Table 3). Data entry was accomplished by the physicians at the ICU.

Simplified Acute Physiology Score II (SAPSII) calculates an estimate of the possibility for death for patients > 18 years treated in a general ICU. It was registered the first 24 hours of the ICU stay and worst measured physiological value was used to calculate the score (Table 5). Data entry was done by the physicians at the ICU.

The number of dressing changes was defined as all dressing changes except the initial operation (index operation) when the OA treatment was initiated. Data was obtained from the EPR.

IAP was measured intermittently and indirectly through the urinary bladder and values given in mmHg. The highest value prior to decompression was reported. Measurements were repeated on a regular basis to detect a sustained elevated IAP.

Table 5: Variables and definition of SAPS II

Variables	Range	Points
Age in years	<40	0
	40-59	7
	60-69	12
	70-74	15
	75-79	16
	≥80	18
Worst value of heart rate	≥160beats/min	7
	120-159beats/min	4
	70-119beats/min	0
	40-69 beats/min	2
	<40beats/min	11
Vorst value of systolic blood pressure	≥200 mmHg	2
	100-199mmHg	0
	70-99mmHg	5
	<70mmHg	13
Lowest value of body temperature	<39 degrees C	0
	≥39 degrees C	3
Lowest ratio of PaO_2/FiO_2, Only if ventilated or CPAP	<100mmHg	11
	100-199mmHg	9
	≥200mmHg	6
Value of urinary output	≥1000ml/d	0
	500-999ml/d	4
	<500ml/d	11
Highest value of serum urea or serum urea nitrogen level	≥30mmol/l	10
	10-29.9mmol/l	6
	<10	0
Worst white blood cells count	<1	12
	1-19	0
	≥20	3
Worst level of K^+, mmol/l	<3 or >5	3
	3-5	0
Worst level of Na^+ , mmol/l	<125	5
	125-144	0
	≥145	1
Worst level of HCO_{3-} , mEq/l	<15	6
	15-19	3
	≥20	0
Worst level of bilirubin, µmol/l	<68.4	0
	68.5-102.5	4
	≥102.6	9
Lowest level of Glasgow Coma Scale	14-15	0
	11-13	5
	9-10	7
	6-8	13
	<6	26
Type of admission	Planned surgical	0
	Medical	6
	Unplanned surgical	8
Chronic diseases	AIDS	17
	Hematologic malignancy	10
	Metastatic cancer	9

Adapted from [76] "A new Simplified Acute Physiology Score (SAPS II) based on a European/North American multicenter study." *JAMA* 270 (24):2957-63.

Classification of OA (Table 6) was done retrospectively for the index operation based on the operative report in the EPR, for Paper I the proposed classification was used, for Papers II and IV the amended classification was used.

Information on RRT was acquired from the ICU-registry and EPR. Length of RRT was reported in days.

Data for assessment if surgery was performed outside normal office hours were obtained from the OR and anesthesia registries.

Table 6: Classification of open abdomen

	Proposed classification(2009)	Amended classification(2016)
Grade 1A	Clean OA without adherence between bowel and abdominal wall or fixity	Clean, no fixation
Grade 1B	Contaminated OA without adherence/fixity	Contaminated, no fixation
Grade 1C		Enteric leak, no fixation
Grade 2A	Clean developing adherence/fixity	Clean, developing fixation
Grade 2B	Contaminated OA developing adherence/fixity	Contaminated, developing fixation
Grade 2C		Enteric leak, developing fixation
Grade 3A	OA complicated by fistula formation	Clean, frozen abdomen
Grade 3B		Contaminated, frozen abdomen
Grade 4	Frozen OA with adherent/fixed bowel; unable to close surgically; with or without fistula	Established enteroatmospheric fistula, frozen abdomen

Adapted from Björck M, Bruhin A, Cheatham M, *et al*: Classification--important step to improve management of patients with an open abdomen. *World J Surg* 2009, 33(6):1154-1157 and Björck, M., A.
W. Kirkpatrick, M. Cheatham, *et al*. 2016. "Amended Classification of the Open Abdomen." Scand J Surg 105 (1):5-10

Blood cultures were drawn on demand due to clinical suspicion of infection and positive cultures with strains after OA was established were registered. At least 30 ml blood was obtained using aseptic technique. Four separate bottles, taken in two series with one aerobic and one anaerobic culture in each were drawn, one from a periphery venipuncture and one from a central access line. The skin was prepared with Chlorhexidine 5mg/ml.

Survival and mortality were reported as in-hospital, 30-, 60- and 90-days.

Clinical data on reasons for OA treatment, comorbidities, primary condition leading to surgery, and surgical procedures were obtained from the EPR.

Workload assessment

For a dressing change to be performed in the OR the following staff was involved: One anesthetist and two nurse anesthetists to take care of the patient during transportation to and from the OR, and providing anesthesia during the dressing change. One surgical assistant lifted the patient to and from the operating table. One scrub nurse and one surgical nurse prepared the equipment and the patient before and after surgery, and assisted throughout the procedure. One senior surgeon with assistance from a junior surgeon performed the dressing change, and two cleaners cleaned the OR and equipment after the procedure was completed.

The dressing change in the ICU was done bedside and personnel involved were the already present ICU nurse and physicist who took care of the already intubated patient and managed opioids, sedatives and muscle relaxants during the dressing change. One scrub nurse and one surgical nurse came from the OR, prepared a small surgical kit and assisted during the procedure. One senior surgeon preformed the dressing change, assisted by a junior surgeon.

Cost assessment

Material cost in Euros from Paper I was calculated for each patient with the cost of the mesh, sutures, V.A.C® therapy kit and rent for the abdominal V.A.C.® Therapy unit and canisters for fluid collection. Personnel cost was calculated based on average wages in Mid-Norway for involved professions and time spent on performing the procedure.

Stratification into dressing changes performed in OR versus ICU

All surgical reports for the study population were reviewed and classified as surgery performed prior to OA treatment, index operation for OA, dressing change as the only procedure, dressing change combined with an additional procedure, surgery not related to the OA, closing of the OA and surgery performed after closure of the OA. Based on information in surgical reports, OR and anesthesia registry, the location of where the procedure took place was identified, i.e. OR or ICU, and was classified into OR; performed in the OR, and ICU; performed at the ICU. For study III of blood stream infection and survival, the cohort of patients was divided into three groups. VAC-OR: having all their dressing changes done in the operating room. VAC-ICU: having all their dressing changes performed at the ICU. VAC-OR/ICU: having dressing changes done in both ICU and OR.

Surgical techniques

OA treatment with vacuum-assisted wound closure with mesh-mediated traction (VAWCM)

After initiating the OA treatment, we used the commercial available abdominal V.A.C.®therapy or ABThera™ device (KCI, San Antonio, Texas, USA). A perforated non-adherent plastic sheet with an encapsulated sponge was placed between the abdominal content and the abdominal wall for protection and prevention of adhesion formation (Fig.8). The plastic sheet was placed deep down into the pelvis, the paracolic gutters, and over the liver after the falciform ligament was divided and ligated. A 30 x 30 cm polypropylene mesh (Prolene®, Ethicon, Inc., Somerville, NJ, USA) was adjusted and sutured to the fascia edges with a running suture, split in the middle and then approximated with a running suture in a loose fashion to make space for the eventually expanding abdominal content. V.A.C.® PEROFORATED GRANUFOAM® ("black/blue

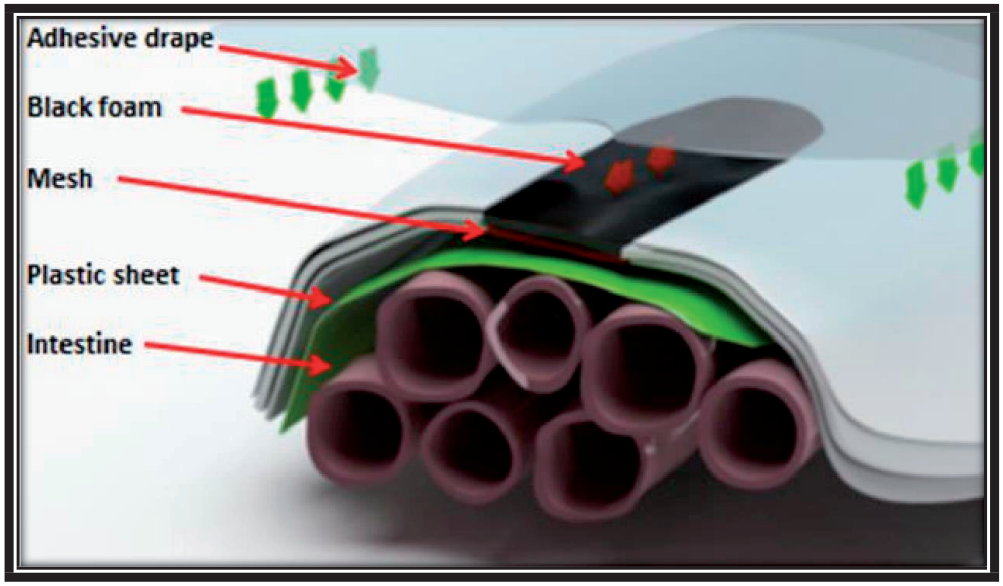

Figure 8: Schematic presentation of the vacuum assisted wound closure with mesh mediated traction (VAWCM).

foam") was adjusted and placed over the mesh to fill the subcutaneous gap. V.A.C® drape was then placed over the black/blue sponge and surrounding skin to seal the bandage (Fig.8). In the

adhesive drape a hole was cut and a suction tube with a self-adhesive drape was positioned and connected to a V.A.C.® Therapy unit set to a continuous negative pressure between 25-150 mmHg. Thereafter the inner and outer dressings were changed completely every second or third day, and the mesh tightened, either in the OR or at the ICU. When closing the OA, the mesh was removed and the fascia closed without tension. The skin was then closed.

OA treatment with vacuum assisted wound closure (VAWC)

After initiating the OA, the commercial available abdominal V.A.C.®therapy or ABThera™ device(KCI, San Antonio, Texas, USA) was used. A perforated non-adherent plastic sheet with an encapsulated sponge was placed between the abdominal content and the abdominal wall for protection and prevention of adhesion formation (Fig.10). The plastic sheet was placed deep down in the pelvis, paracolic gutters, and over the liver after the falciform ligament was divided and ligated. V.A.C.® PERFORATED GRANUFOAM® ("black/blue sponge") was adjusted and placed over the plastic sheet to fill the gap in the rectus fascia and subcutaneous fat to enable a traction to the fascia and sub cutis. V.A.C® drape was then placed over the black or blue sponge and surrounding skin to

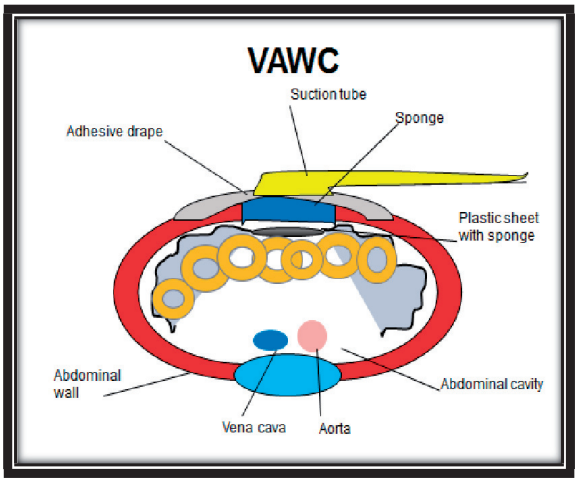

Figure 9: Schematic presentation of vacuum assisted wound closure (VAWC)

seal the bandage. A hole was cut in the adhesive drape and a suction tube with a self-adhesive drape was positioned into the hole and connected to a V.A.C.® Therapy unit set to a continuous negative pressure between 25-150 mmHg. Thereafter the inner and outer dressings were changed completely every second or third day, either at the OR or at the ICU. When closing the OA, all foams and plastic sheets were completely removed and the rectus fascia closed tension free with interrupted or continuous sutures. The skin was then closed.

Chimney-VAC

This is our own newly invented procedure to deal with intestinal leaks and EAF in the OA when deviation of the intestinal leakage through other techniques is impossible. The advantage of this method seems to be that drainage of the fistula and the OA in the same source to avoid intestinal fluid to be collected inside the abdominal cavity. This may be the situation when using a separate drainage for the fistula and the OA with the risk of leakage from the fistula against the NPWT source. The exposed intestine was covered with a non-adherent plastic sheet from the abdominal V.A.C.®therapy or ABThera™ kit and a window was made for the fistula(Fig.10). A one layer V.A.C. White-Foam™ (KCI, San Antonio, Texas, USA) with an opening for the fistula was placed over the plastic sheet. Subsequently a 15mm diameter chimney was made out of another piece of White-Foam™, armored with a soft plastic tube or stainless steel sutures (Ethicon, Somerville, NJ, USA) to prevent collapse. If not already in place, a polypropylene mesh (Prolene®, Ethicon, Inc., Somerville, NJ, USA) was adjusted and sutured to the fascia. The mesh with an opening for the chimney was then split in the middle and tightened over the white foam, to prevent further

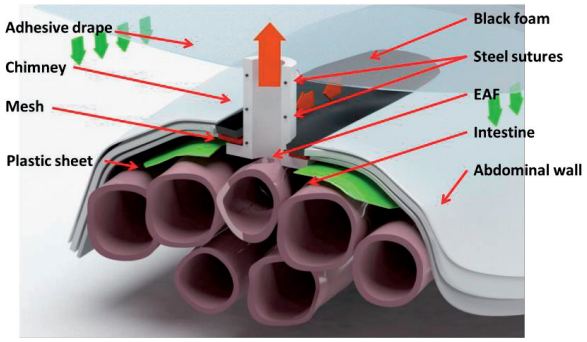

Figure 10: Schematic presentation of the Chimney-VAC

retraction of the rectus fascia (Fig.11). Then the mesh was covered with a sponge and adhesive drape with an opening for the chimney, and the connector to vacuum pump was placed on top of the chimney (Fig.12). The V.A.C.® Therapy unit was set to a continuous negative pressure of 25-75mmHg and the dressing was changed every 48 to 72 hours. The foams and plastic sheet were removed and a new plastic drape was placed, a new chimney made and placed in a similar way as earlier, and the mesh was tightened if possible, to reduce the gap between fascial edges. Treatment with regular dressing changes was performed until the fascia and skin could be closed and an entero-cutaneous fistula was established.

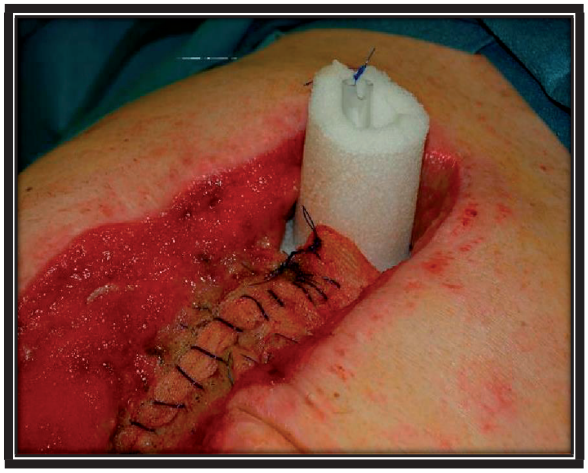

Figure 11: Mesh tightened around the chimney

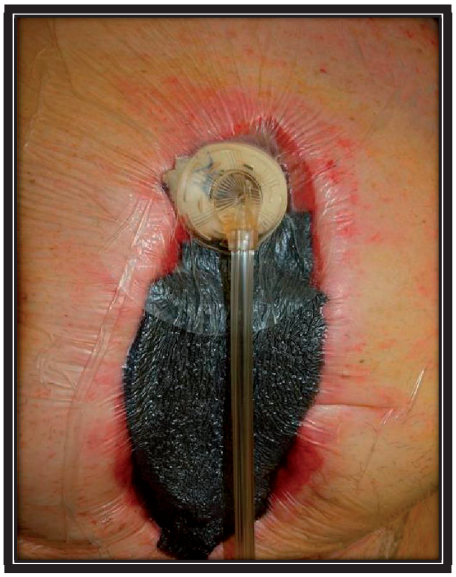

Figure 12: Vacuum source on top of the chimney

Statistics

Data were analyzed in Excel, Windows 2010 and IBM SPSS software, version 21. The statistical significance level was set to $p < 0.05$, two-tailed. Continuous data were presented as median with range or mean with 95% confidence interval (CI), dependent on distribution of the data. Between groups comparisons of continuous variables were performed with Mann Whitney Test (non-parametric) or students-t test and one-way ANOVA (parametric), and in case of extreme skewness transformation were used. Statistical comparisons of the duration of the VAC change, including total time, surgical time, and duration of anesthesia in ICU compared to OR were performed with an independent t-test. Categorical variables were compared using Pearson Chi-Square test or Fisher's exact test. Cox-regression analysis for survival dependent on where the dressing change took place was adjusted for age, gender, RRT, SAPSII and incidence of BSI. Clinical variables included in univariate analyses for survival were age, SAPS II, gender, ACS, RRT and presence of cardiovascular disease. The variables associated with survival with a $p < 0.05$ in univariate analyses were included in a multivariable logistic regression analysis and were expressed as odds ratios with 95% CI. The variables age, ACS, RRT, SAPS II and pre-existing cardiovascular disease were entered as a forward stepwise regression in the multivariate analysis and variables with $p < 0.05$ were kept in the final model, excluding SAPSII and preexisting cardiovascular disease.

ETHICS

The studies were approved by the Regional Ethics Committee in Mid-Norway, 2014/957.

SUMMARY OF PAPERS

Paper I

Background: ACS is a serious and life threatening complication after aortic surgery, and prompt identification and treatment is required if present. The aim of this study was to report early experiences with OA using VAWCM and abdominal V.A.C.therapy (KCI medical, San Antonio, TX, USA).

Material and methods: In this prospective study, nine consecutive patients treated with OA after surgery for ruptured or intact abdominal aortic aneurysm from October 2006 to April 2009 were included. Seven were treated for ACS with decompressive laparotomy and two patients were left open with a TAC after the initially aortic repair. The diagnosis of ACS was defined as a sustained IAP> 20mmHg (with or without an APP <60mmHg) and a new organ failure, and IAP was measured with the Foley Manometry method. Patients were classified with a new proposed classification of OA. The negative pressure was limited to 75mmHg due to fear of development of intestinal fistulas. Dressing changes were performed every second or third day with tightening of the mesh until the fascia edges could be sutured in the midline with a tension free closure.

Results: Respiratory failure was developed in three patients, renal failure in one patient and a combination of renal and respiratory failure was detected in three patients with ACS. Six patients with ACS had their organ failure(s) reversed by the decompressive laparotomy and survived, one patient died seven days after decompression due to multi-organ failure. Two patients died later due to irreversible organ failure, 28 and 39 days after ending the OA treatment, respectively. The OA could be closed with a delayed primary fascial closure for eight of the patients after a median of four (range 2-7) dressing changes and 10.5 (range 6-19) days. All patients were graded as 1A. The material costs varied from 1547 to 3630€ for the individual patient. Necrosis of the sigmoid part of the colon was found in two patients and treated with resection and colostomy. Intra-abdominal abscesses, graft infection and intestinal fistulas were

not observed. After a mean follow up of 17 (range 2-36) months, two small incisional hernias were clinically detected.

Conclusion: In this study we found that decompressive laparotomy was an effective treatment for ACS with reversal of organ failures. We also conclude that the VAWCM for temporary closure of the abdominal wound was a feasible method with few side effects.

Paper II

Background: An enteric fistula in a patient with an OA is a severe condition and challenging for both the patient and the team caring for the patient. One treatment option for intestinal leakage in OA is to repair the defect in the intestine and cover it with the gastro-colic omentum and continue the NPWT. Another option is to deviate the intestinal leakage and create an entero-cutan fistula, or more preferable, construct a stoma and then continue with NPWT until the OA is closed. When definitive repair or deviation is not possible, mostly due to adhesions and fixation between edematous intestinal loops and abdominal wall preventing adequate mobilization of the intestine, the patient ends with an EAF, classified as Grade 4 OA. The intestinal fluid leakage in the open abdomen will lead to an ongoing contamination and a severe inflammatory response which might be life threatening. The main goal of the treatment is to drain the intestinal content out of the abdomen to avoid peritonitis, and gradually close the abdominal wound. Methods available today use a separate stoma bag and a negative suction device, and often the patient end with a giant hernia and an entero-cutan fistula.

Material and methods: This was a technical report of a novel invented method at St. Olavs Hospital, Chimney-VAC, to treat patients with EAF. The method combines drainage of the fistula and the OA with mesh mediated traction. The vacuum source is connected on top of a chimney made out of V.A.C. White Foam™ (KCI, San Antonio, Texas, US) which is placed over the fistula opening and maintains to drain the fistula and provide a negative pressure in the OA. Two illustrative patient cases were included, and the new surgical procedure is described in detail for both with the necessary individual adjustments that can be made using this method. Other in-hospital treatments and results at discharge were reported for two patients, one 63-years old man with Crohn's disease with an anastomotic leakage present eight days after an ileocolic resection, and a 39-years old man with a small intestinal leakage six days after laparotomy for peritonitis with right sided colectomy and ileostomy.

Results: This technical report presents two patients treated with Chimney-VAC. The abdominal wound could be closed after two and four weeks. The EAF was converted to an

enterocutaneous fistula and stoma formation was achieved after additional two and four weeks. Both patients survived and could be discharged from the hospital after 55 and 215 days, respectively. This approach prevented most of the intestinal content to reach the open wound, as the drainage of the open abdomen was adequate through the chimney.

Conclusion: The Chimney-VAC seems to be a feasible and promising method for treatment of grade 4 OAs. Still, more research is needed and the method has to be evaluated in a broader setting including more patients and hospitals.

Paper III

Background: Patients with OA need repeated dressing changes and minor surgical procedures throughout the hospital stay. OA treatment is demanding for the staff at the ICU and the OR, and planned dressing changes often come in conflict with other patients in need of the OR for emergency surgery. An alternative approach is to perform the dressing change procedures in the ICU. The aim of this paper was to assess whether OA dressing changes performed at the ICU with its more contaminated environment is as safe as in the OR. Other aims were to evaluate personnel costs and time used for performing the dressing changes, Furthermore to evaluate if the use of ICU might facilitate more of the dressing changes to be performed during office hours with more of the regular staff available providing a continuum of the OA treatment.

Material and methods: Retrospective study of 98 patients with OA in need for ICU treatment and dressing changes from October 2006 to June 2014. Data were obtained from registered procedure codes, clinical and administrative patient records and the OR, ICU, anesthesia and microbiology databases. Outcomes were 30-, 60-, and 90-days survival, occurrence of BSI, and time used by the staff of the OR and anesthesia, and personnel costs for performing the dressing changes. Patients were analyzed in three groups for survival and BSI occurrence, dependent on where the dressing changes for OA took place; only in the OR or only in the ICU, or partly at an OR and partly at the ICU. Time used and personnel costs for dressing changes were analyzed and compared between those done in the OR or in the ICU. A total of 960 surgical procedures were performed, including 552 dressing changes of which 165 were done at the ICU.

Results: The mean duration for the surgical team performing a VAC change in the ICU was 63.4 (60.4-66.4) minutes and in the OR 98.2 (94.6-101.8) minutes ($p<0.001$). The mean duration for the anesthesia team at the OR was 115.5 minutes, while this team was not present at the ICU. All dressing changes scheduled for the ICU except of one could be completed in the ICU. Personnel costs were reduced with 682€/procedure when using the ICU. Forty-two patients had all the VAC-changes done in the OR (VAC-OR), 22 in the ICU (VAC-ICU) and 34 in both OR and

ICU (VAC-OR/ICU). The presence of BSI was 8 (19%) in the VAC-OR patients, 7 (32%) in the VAC-ICU and 8 (24%) in the VAC-OR/ICU (p=0.509). Thirty-five patients (83%) survived 30 days in the VAC-OR group, 17 in the VAC-ICU group (77%) and 28 (82%) in the VAC-OR/ICU group (p=0.844). Dressing changes performed during office hours at the ICU was 93 out of 165 (56%), the same as in the OR with 157 out of 278 (56%) (p=1).

Conclusion: This was the first study comparing the outcomes for OA patients having dressing changes performed in the OR or at the ICU. The results indicate that this practice seemed to be safe for the patient regarding BSI and survival, and it saves time for the OR and anesthesia team with subsequent reduction of personnel costs. Avoiding dressing changes in the OR did not result in more procedures performed during office hours.

Paper IV

Background: OA is demanding for both the patients and the hospital staff in care for the treatment, and it is associated with a considerable mortality. The main aim of this study was to report survival and cause of mortality after OA. Secondary aims were to evaluate length of stay (LOS) in the intensive care unit (ICU) and in hospital, time to abdominal closure, delayed fascial closure rate and major complications.

Material and methods: This was a study of all consecutive patients treated with OA at St. Olavs Hospital between October 2006 and June 2014. Patients were identified from two prospective databases, the hospital's patient administrative system and the Norwegian Vascular Registry (NORKAR). Data were collected from the same databases as used in paper III with prospectively collected data.

Results: The 118 patients identified with OA had a median age of 63 (20-88) years and 82 (69%) were men. Indications for OA treatment were ACS (n=53), prophylactic open abdomen (n=29), abdominal contamination/second look laparotomy (n=22), necrotizing fasciitis (n=7), hemorrhage packing (n=4), and full thickness wound dehiscence (n=3). AAA was the most common diagnosis (38%), and aortic repair and bowel resections were the most common surgical procedures prior to or at the index operation for OA. Eight per cent were trauma patients. VAWCM was used in 92 (78%) patients, the remaining 26 (22%) had VAWC only. Per-protocol primary fascial closure rate was 84%, 14% needed reconstruction of the abdominal wall with a mesh or skin/fascial flaps, only two patients were left with a giant hernia. Median time to abdominal closure was 12 days (1-143) and median number TAC procedures was five (1-32) before closure or death. Median LOS in the ICU was 15 (1-89) days, and in-hospital LOS was 29(1-246) days. Nine patients, all after previous surgery to the gastrointestinal tract, developed EAF, and all of them survived. Five were treated with Chimney-VAC. EAF patients were treated with OA for 29 (10-88) days and the median number of dressing changes was 14 (7-32). Eighty-one (68%) patients survived the hospital stay. Non-survivors had a median of three (2-5) organ failures and died 13 (0-80) days after established OA. Nine patients underwent additional

procedures due to bleeding, four of them died despite advanced intervention. Renal failure requiring RRT (OR: 3.9, 95%CI: 1.37-11.11), ACS (OR: 3.1, 95%CI: 1.19-8.29) and advanced age (OR: 1.045, 95%CI: 1.004-1.088) were independent predictors of mortality.

Conclusion: Treating patients with OA is resource demanding with multiple reoperations and prolonged stay in the ICU and hospital. NPWT seems to be a feasible kind of TAC with few serious adverse effects. Most patients had their OA closed with primary fascial suture. Two thirds survived the open abdomen and renal failure with RRT, ACS and advanced age were predictors of mortality. Presence of EAF was not associated with poorer outcomes as all patients with an EAF survived.

GENERAL DISCUSSION OF RESULTS

In the current thesis recently developed advances (VAWCM) and novel (VAC-chimney) treatment approaches to OA and factors related to outcomes after OA were studied. The work demonstrated how advances in treatment help to reduce and even prevent dreaded complications, as well as to save hospital resources with regard to personnel, space and equipment, without compromising patient safety. Furthermore, the studies identified risk factors associated with mortality and morbidity in OA, these included ACS as primary cause for OA, age and RRT. The clinicians need to take these factors into consideration in the follow up of patients at risk for ACS and OA.

Obtaining fascial closure is an important goal in order to avoid giant abdominal hernias in OA patients surviving OA. Study I showed that with VAWCM delayed fascial closure was achieved in all patients surviving OA after aortic surgery. This is in line with a newly published review on OA treatment with a per protocol closure rate between 79 % to 100 % [77], as well as a prospective study with OA after aortic surgery with delayed fascial closure in all 25 patients surviving OA [28]. In study IV, including all 118 OA patients treated with NPWT at St. Olavs Hospital, the per-protocol fascial closure rate was 84%, and only two patients ended up with a giant hernia after 107 and 143 days of OA treatment, respectively. The first report on this method had a 100% per-protocol fascial closure rate in 7 patients with mixed primary causes of OA [49]. The larger follow up study to this in 111 OA patients (mainly vascular, gastrointestinal or trauma diagnoses) had a per-protocol fascial closure of 89%, and no patient was left with a giant hernia [55]. This is similar to the results in study IV. Also a study from Austria of NPWT combined with dynamic retention sutures of the rectus fascia in patients with peritonitis reported comparable results to study IV with a per protocol delayed fascial closure of 87% and two patients left with a giant hernia. [78]. However, an overall rate of giant hernias and split skin grafting of 27% was reported in 173 non-trauma patients treated with NPWT in a retrospective study from USA [79]. This poor result compared to the 0-2% of giant hernias in OA patients in the aforementioned

studies, may be due to too low tension of the rectus fascia. Indeed, another successful approach to OA treatment described by Hougaard and colleagues who implemented increased fascial traction through positioning one foam underneath the rectus fascia connected to one foam between the rectus fascia with a negative pressure of 125 mmHg gave a 92% fascial closure rate, but note that occurrence of giant hernias was not reported [80]. Taken together, it seems that the best OA result is obtained with negative pressures treatment and traction to the rectus fascia. This is in line with an earlier review by Atema et al. that reported the highest delayed fascial closure rates in patients treated with NPWT and fascial traction, but the quality of the included studies was low [81]. The importance of fascial traction for successful OA treatment has been clearly demonstrated in a study with NPWT without fascial traction where primary fascial closure was successfully achieved in only 2% of OAs lasting for more than 12 days [79]. A study from Finland has also shown the significance of applying traction to the fascia in addition to NPWT [82]. Lack of closure was present in 47% of the OA patients without traction to the fascia, and in only 10% of patients in the fascia traction group, and all of these ended with a planned incisional hernia [82]. The results in study I and IV provide further support for VAWCM's superior performance when it comes to obtaining successful delayed fascial closure, and based on the available data, VAWCM should be considered as the method of choice for OA.

Closure time is an important factor for both the patient and the hospital. In study I, OA after aortic repair was closed after a median of 10.5 days while in study IV with a more mixed population consisting also of patients with gastrointestinal diseases and trauma patients, the median closure time was 12.0 days. Both these closure times are shorter than in previous reports. The first VAWCM publication had a median delayed fascial closure time of 32 days [49], while a prospective study after aortic surgery reported a median delay of 15 days [28], and in a mixed patient cohort a median delay of 14 days was reported [55]. However, in those studies only patients in need of more than five days of OA treatment were included. If only including patients treated for more than five days, the median time to closure was 13 days in the St. Olav cohort too, i.e. the same as in the prospective Swedish studies. Time to closure

appear to have a bimodal distribution; a few patients can be closed early (≤5 days) while the majority of patients are treated for a median of 2 weeks, and in some selected patients OA may last for several months.

Performing the OA dressing change in the ICU saved on average 30 minutes per procedure for the surgical team and almost two hours for the anesthesia team, with an estimated cost reduction of 682 EUR for each dressing change, and it was as safe for the patient as using the OR (Study III). Several reports have described major and minor surgery performed outside the OR [65-73, 82, 83], but to our knowledge study III is the first to directly compare time and costs spent performing similar dressing change in two different locations; the OR and the ICU. It should be acknowledged, however, that the patients were not randomized, and residual confounding cannot be out-ruled.

Surprisingly, utilizing the ICU for dressing changes did not lead to a higher proportion of the procedures performed during office hours. It may be speculated that this was due to the general logistics of OA treatment at the departments of surgery and anesthesia. OA dressing changes are defined as emergency procedures at St. Olavs Hospital, but even more emergent surgeries will be prioritized before OA changes, delaying the procedure until OR staff is available. Altering OA dressing change status to planned procedures, and assigning daytime personnel to the ICU, could possibly lead to more procedures being performed during office hours. This is an important goal, as several studies report less favorable outcomes of procedures performed outside of regular working hours [69, 84-86]. Thus, the management of OA dressing changes should ideally be during normal working hours to reduce the risk of inexperienced surgeons managing complicated surgical wounds on their own and to avoid the risk of potentially life threatening complications [55, 59].

In study III, the same surgical team performed the procedure in much the same manner in both

the OR and the ICU. Hence, most of the time saved was generated by no patient transport, shorter preparation times, and reduction in required anesthesia personnel. Furthermore, the surgical kit used in the ICU was trimmed and needed less preparation before surgery. Personnel is a limited resource, also for emergency surgery, and it has previously been reported that OR nurses are not required when performing surgery at the ICU, as trained ICU nurses can assist during surgical procedures [69]. However, at St. Olavs Hospital the surgical nurses from the OR assisted the surgeons when performing surgery at the ICU. Indeed, the same nurses assisted in the procedures in the ICU and the OR. On occasion, OR nurses are a limited resource due to more urgent emergency surgery in need of the OR staff. To avoid this limitation of available staff, ICU nurses should be trained to assist during OA dressing changes. The substituted OR nurse would then be available for more urgent emergency patient in the OR, while the ICU dressing change of OA could go as planned with less OR personnel. This would provide a significant gain in available personnel with highly specialized competence. This approach might increase the amount of OA patients treated as scheduled. Another approach is to implement a strict protocol which defines the patients suitable for dressing changes to be done at the ICU [71]. Yet another way to organize the dressing changes could be to use OR nurses and surgeons allocated for planned daytime surgery. This would secure that the procedure takes place during office hours. However, a negative consequence could be delayed treatment for patients in need for elective surgery. Altogether, utilizing the ICU during daytime with allocated surgeons and trained ICU nurses assisting the surgeon appears most convenient for improving OA treatment as well as logistics of emergency and planned surgery in general.

In the present study only one out of 165 dressing changes at the ICU was aborted and the patient transferred to the OR to complete the procedure. The reasons for moving to the OR were unexpected findings of pancreatic necrosis with the need of more extensive washout and debridement of the abdominal cavity. This was a clinical situation which might have the potential of complications of major bleeding from large vessels or damage to the intestines, and therefore the need of a complete and fully equipped OR. Nevertheless, the present results showed that bedside ICU surgery with dressing change as the only procedure could be

completed as planned in most cases, despite the lack of a more strict protocol as encouraged by others [71]. When the team knows beforehand that more extensive surgery would be necessary, the procedure should be performed in an OR. It was not possible to analyze the reason for why the ICU or OR was chosen as location when dressing change was the only planned procedure to be performed, neither we have analyzed if the 109 dressing changes with an additional procedure were planned or became necessary during the dressing change. A prospective design collecting preoperative choice and reasons for choice is needed to answer this question. However, study III showed that surgeons in the vast majority of cases were able to determine which dressing changes could be performed at the ICU, and most likely there is a large potential for transferring more OA procedures from the OR to the ICU and thus saving both time and personnel.

Each of the 164 completed dressing changes at the ICU saved St. Olavs Hospital for 682€ in personnel costs. This constituted a cost reduction of 110 000 €, and if all dressing changes were performed at the ICU, more than 300 000 € would be saved during the study period. Cost reductions are also reported in other studies comparing the costs of several kinds of surgical procedures performed at the ICU and the OR [71]. The savings obtained by performing the surgery at the ICU at St. Olavs Hospital were lower compared to previously reports. This is due to cost being highly dependent on differences in salaries and OR charges between countries. Also, by using ICU nurses instead of OR nurses as suggested above, further cost reductions might be achieved.

BSI was detected in 23% of the OA-patients treated at the ICU. This is in line with several other studies reporting a high percentage of OA patients having BSI [30, 79, 87, 88]. It seems that OA patients have a higher percentage of BSI than the general ICU population [89, 90]. BSI has a heterogonous etiology in ICU patients, and can be caused by ventilator-associated pneumonia, intravenous catheter induced infection, urinary tract infections, among others. With a prospective design including a strict protocol for drawing blood samples and mapping of

infection foci, insights into causes of BSI and whether using the ICU for dressing changes are associated with specific types of infection(s) might be uncovered. In general, avoiding BSI is important as it increases both ICU and in-hospital mortality [90]. However, we were not able to demonstrate that the higher prevalence of BSI in the ICU treated group led to higher SAPSII, longer LOS or increased mortality. This may be due to the low power in study III increasing the risk of type II statistical error. The low volume of patients treated with OA at St. Olavs Hospital each year makes it inherently difficult to design a local study with sufficient power to detect the influence of BSI on survival [89]. Prospective multi-center studies with strict clinical protocols are needed to fully investigate this issue.

EAF is a feared complication of OA treatment. It was present in 7.6% of the patients, of whom all survived the hospital stay in study IV. The rate of EAF vary wildly between studies, from 0%-60 % in a non-trauma cohort [81] and 5% in trauma patients [91]. The rate of EAF in study IV is in the lower end of this range, and the survival was 100% in these patients. Intestinal leakage, such as seen in grade 4 OA [58, 81] is a very serious complication since it maintains an inflammatory response in the patient [59, 92]. Studies have reported mortality between 24 %-88% among patients with a Grade 4 OA [51, 54-56]. However, mortality may be reduced if patients are treated in specialized centers for intestinal failure [93]. Therefore, the approach used at St. Olavs hospital seems to be highly successful. Different methods to deal with theenteric leak in OA have been introduced [92, 94]. My coworkers and I developed and introduced the Chimney VAC in 2013 with the aim of improving treatment for EAF. We place the connection to the VAC Therapy on top of the fistula with a chimney made out of White Foam. This is important for sealing of the fistula and preventing further leakage of intestinal fluid into the OA. This technique also secures drainage of the OA without spilling intestinal fluid, which would occur if the negative pressure source is placed away from the fistula.

The Chimney VAC approach was evaluated in five patients with grade 4 OA in Study IV, and the results showed that it was possible to close the OA and convert the free leakage of intestinal

fluids into an entero-cutan fistula in all patients, with no mortality. All patients at St. Olavs Hospital with intestinal leakage had undergone gastrointestinal tract surgery, which is in accordance with other reports [54, 91]. Treatment of EAF is demanding, requiring a multidisciplinary approach involving surgeons, ICU staff, and specialized stoma therapists as well as competent staff members at the general ward and the outpatient clinic [59, 94]. That may improve patient outcomes and save sufferings and costs.

Survival of patients treated with OA is dependent on the reason for the OA. In study IV, in-hospital survival was 68% for all consecutive patients treated with OA in this mixed surgical and internal medicine cohort. This is comparable to what has been reported in the literature. In a newly published review including patients mainly treated for peritonitis the survival rates varied between 33% -100 % [81]. In a prospective study by Sörelius et al. the 30-days survival after aortic repair and OA with VAWCM was 73% [28], while in-hospital survival was between 46-80% in a recent review of OA after aortic repair with different TACs [77]. Two prospective studies with mixed surgical cohorts, one from Great Britain and one from Sweden [51, 55], reported in- hospital survival of 72.8% and 70.2%, respectively. In a prospective study including only traumapatients, the overall survival was 76.9 % [91], and in a prospective multicenter study including 280 patients, mostly trauma patients, the overall in-hospital survival was 85% [95]. A Danish study in which most of the patients had peritonitis reported in-hospital survival of 83% [80]. These studies demonstrate quite substantial differences in survival in OA patients, which may be related to the underlying clinical cause of OA. The present studies I, III and IV point to ACS as the most important clinical factors related to survival in patients with OA. In study IV it was shown that presence of ACS was a strong predictor for death among those treated with OA, increasing the odds ratio (OR) for death almost threefold. This is in line with other reports with high mortality rates for patients treated for ACS [36, 39, 82, 96], as well as increased survival in OA patient groups with low prevalence of ACS, such as in a study from Great Britain including only 2.1% ACS patients and in the Swedish prospective study with 20% ACS patients [51, 55]. It seems that ACS associated with aortic surgery [96, 97] or endovascular intervention has a particular high mortality [27]. Study I provides some support for that, as 7

out of 9 patients were treated with decompression laparotomy after aortic surgery had ACS, but despite the active intervention, only a little more than 50% (n=4) of the ACS patients survived the hospital stay.

The pathophysiological processes in ACS are multifactorial and may depend on the primary cause of the ACS. Still, the present work together with previous literature do demonstrate the importance of avoiding ACS with preventive measures and close monitoring of the patients.

This was a single center study reporting results of OA treatment in a tertiary referral hospital. Our approach and patient care might be quite different from those at other hospitals, and therefore generalizability may be reduced which should be taken into consideration when evaluating the outcomes of the present studies [98]. The potential of biased results due to local treatment adjustments might have been avoided if the studies had been designed with more participating hospitals as a multi-center controlled trial [99]. However, in clinical medicine, study designs with retrospective data collection and un-blinded treatment are an inherent part of surgical research to achieve best clinical practice for the patients, especially when considering rare life-threatening clinical situations [100].

To obtain sufficient power to examine the impact of treatment schemes, clinical and demographic variables for OA treatment, a multi-site, international collaboration study would be necessary. For instance, a Scandinavian study might be a good solution since the health care systems in Scandinavian countries are quite similar. Moreover, with several sites it could be possible to perform a randomized controlled trial (RCT). Implementing an RCT is challenging; it demands that the department allocate time, personnel and financial support to complete the study in the appropriate way [54, 101]. The RCT design depends on strict criteria to obtain proper standardization to ensure comparative groups, which often results in many patients not

meeting all the inclusion criteria. Thus, the representativeness of the sample may be questioned, which in turn may impact on the generalization value of the study. Despite inviting several hospitals to include participants in a multi-site OA study, the low OA incidence will limit the recruitment, and it may be difficult to reach the necessary power to complete a study within a reasonable time frame[101, 102]. As an example, in order to evaluate a significant improvement in survival or fascial closure from 50 % to 70 %, more than one-hundred patients in each group would be necessary when comparing different methods for OA treatment.
A strict protocol with prospective design would secure that all measurements were obtained from every participant at predefined time points throughout the study. In the present studies, we used measurements obtained in a clinical setting. For instance, blood cultures were drawn on demand, with the possibility for missing positive blood cultures, especially in patients who died early during the hospital stay. Additionally, grading of OA was done retrospectively, with the chance of misinterpreting the findings described in the EPR. Moreover, patients were notallocated into a specific treatment group (e.g. ICU only or OR only). All these issues might have biased the selection for where the dressing changes took place, i.e. favoring the use of ICU for patients in need of ongoing inotrope medication, respiratory or renal support.

Also, other complications such as pneumonia, wound infections, urinary tract infections, delayed per oral nutrition and weight loss might be more accurate reported in a prospective trial. A prospective trial might also identify more accurate reasons for organ failure than ACS such as anastomotic leakage or pneumonia. In contrast, patient cohorts consisting of every case with a predefined condition from a given time period, i.e. here the OA, may better describe the outcomes of all patients with this condition treated in a routine setting, and for that reason, the present results may be as important as the outcomes of selected cohorts within an RCT. Moreover, the studies in this thesis include as detailed descriptions of measurements as were possible to obtain. Since these are all standard measurements, it should be possible for other institutions to compare their experiences with those of the present studies.

CONCLUSIONS

It is important to improve surgical practice, and treatment for OA with VAWCM seems to be a feasible way to deal with open abdomen patients. When complicated with an EAF, the use of Chimney-VAC undertakes drainage of intestinal fluid out of the abdominal cavity and helps creating a controlled entero-cutan fistula.

The results of this thesis may provide better practices for both patients and hospitals, and it seems to be safe to use the ICU as an OR for repeated dressing changes for OA in respect of survival and blood stream infection. This approach saves time and resources for the hospital.

OA is rare and it may be difficult to study at one single hospital, even at a tertiary referral one such as St. Olavs Hospital. Still, retrospective studies in combination with registries are useful approaches to evaluate and improve surgical practice. Despite the severity an open abdomen represents, two-thirds of the patients survived. Increased mortality is related to high age, ACS and the need of dialysis during OA treatment.

FURTHER PERSPECTIVES

It seems appropriate to design and perform a prospective multi-center study on Chimney-VAC to evaluate inflammatory response when using this method compared to other available techniques for dealing with EAF jin the open abdomen setting.

A prospective observational study on patients in the ICU with measuring IAP to detect IAH and to make interventions before ACS is established seems warranted, as survival may be improved when treatment is started before organ failure has developed.

It might be useful to merge data from several studies in order to decide the best treatment option for patients with open abdomen, or preferably to perform a multi-center prospective study on different strategies for treatment of open abdomen.

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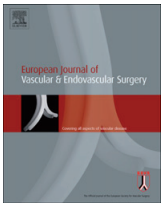
Paper I

Eur J Vasc Endovasc Surg (2010) **40**, 60—64



Early Results after Treatment of Open Abdomen after Aortic Surgery with Mesh Traction and Vacuum-Assisted Wound Closure

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Abdominal compartment syndrome (ACS);
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Ruptured abdominal aortic aneurysm (rAAA);
Vacuum-assisted wound closure (VAWC)

Abstract *Objectives:* This study aimed to describe the use of vacuum-assisted wound closure (VAWC) and mesh traction to repair an open abdomen after aortic surgery.
Design: Prospective clinical study.
Material and methods: From October 2006 to April 2009, nine consecutive patients were treated; seven of the patients received laparostomy following abdominal compartment syndrome (ACS), while two wounds were left open initially. The indication for laparostomy was intra-abdominal pressure (IAP) $>$ 20 mmHg or abdominal perfusion pressure (APP) $<$ 60 mmHg and development of organ failure. V.A.C. therapy (KCI, San Antonio, TX, USA) was initiated with the laparostomy, and supplemented with a fascial mesh after 2 days. The wound was then closed stepwise with mesh traction and VAWC.
Results: All wounds could be closed following a median interval of 10.5 (range: 6—19) days after laparostomy. A median of four (range: 2—7) dressing changes were performed. One patient died on the seventh postoperative day. Two other patients died 38 and 50 days after final closure, respectively. Left colonic necrosis was seen in two patients while incisional hernia was observed in two patients. Mean follow-up duration was 17 (range: 2—36) months.
Conclusion: VAWC with mesh traction was successful in terms of early delayed primary closure and is a useful tool in the treatment of open abdomen after aortic surgery.

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The abdominal compartment syndrome (ACS) was described by Kron *et al*. in 1984[1] and later by Fietsam.[2] It is caused by increased intra-abdominal volume or extrinsic compression of the abdominal wall, and may accompany the retroperitoneal haematoma usually observed following ruptured abdominal aneurysm repair.[3] The true incidence of ACS after aortic surgery is unknown[4], but in one study, seven out of 27 patients developed ACS after surgery for ruptured aortic aneurysm.[5] In two studies of ruptured abdominal aortic aneurysm (rAAA) treated with endovascular aneurysm repair (EVAR), 20% developed ACS.[6,7] If not recognised and treated, ACS may lead to progressive organ failure and death.[2,8] The treatment of choice is prompt decompressive laparotomy. In our department, awareness of this condition has increased during recent years,[9] partly due to the consensus report from the World Society of Abdominal Compartment Syndrome (www.wsacs.org) and the increasing number of publications on this topic. Several methods for temporary abdominal closure (TAC) have been described.[10–18] After the introduction of a vacuum-assisted closure system, the care of patients with decompressive laparotomy has become easier. This article describes the practical use and early results of the V.A.C. therapy (KCI, San Antonio, Texas, USA) combined with mesh traction after aortic aneurysm surgery.[18]

Material and Methods

Data were gathered prospectively. Altogether, nine patients were included in a consecutive series where the abdomen was left open after repair of rAAA ($n = 8$) or elective type IV thoracoabdominal aneurysm repair ($n = 1$)from October 2006 to April 2009 (Table 1). The total number of patients treated for AAA during the study period was 239, including 42 open aneurysm repair (OAR) and nine EVAR for rAAA. Of the patients included in this study, seven were treated with OAR and two by EVAR. In two cases, the V.A.C. therapy was applied at the end of the initial operation since the fascia could not be closed without considerable tension. In the other cases, laparostomy was done after measurement of an elevated intra-abdominal pressure (IAP)[1,19] $>$ 20 mmHg or abdominal perfusion pressure (APP) $<$ 60 mmHg and signs of organ failure. One patient developed organ failure with a tense abdomen; the IAP was 12 mmHg and mean arterial pressure (MAP) was 55 mmHg, giving an APP of 43 mmHg. All nine had a clean open abdomen without any adhesions or fixity, classified as grade 1A.[20] The distances between the fascial edges were not measured. The V.A.C. therapy combined with mesh traction technique is described in detail elsewhere,[18] and only a short description is given here. After completing the decompressive laparotomy, the intestines are protected by a foam sheet covered by plastic film to prevent the formation of adhesions between the intestines and the abdominal wall. This coverage allows the fascia to slide over the dressing. An outer sponge secured by a plastic drape covers the abdominal defect. Vacuum is applied at a continuous pressure of 75 mmHg. After 2 days, the dressing is changed and the abdominal wall is closed, provided this can be done without tension. If not, the dressing is changed completely and a Prolene® (Ethicon, Inc., Somerville, NJ, USA) mesh 30 $\times$ 30 cm, is sutured to the fascial edges with a running monofilament suture and then split in the midline. The mesh edges are approximated in a loose fashion, and then sutured together (Fig. 1). Thereafter, the sponge and plastic drape are applied as previously described. A schematic representation of technique is given in Fig. 2. The dressing is changed every second or third day. The mesh is cut and approximated in the midline until the fascial edges can be closed by a delayed primary suture. After removal of the mesh, the

Table 1 Patient characteristics and details on treatment of open abdomen.

Case #	Sex	Age (years)	Diagnosis	IAP mmHg	Organ failure	Days after aortic repair	Days with vacuum treatment	# of dressing changes	Follow-up (months)	Results	Cost (in Euros)
1	male	55	rAAA	40	O, RF	1	19	7	36	Small hernia,	3630
2	female	85	rAAA	25	O, RF	1	7	3	26	Fully recovered	1986
3	male	71	rAAA	20	O, RF	4	13	6	14	Fully recovered	3520
4	male	70	rAAA	LO			12	5	12	Fully recovered, small hernia	2570
5	male	76	rAAA	28	RF	5		2	—	Deceased	
6	male	66	Th-AAA	12	RF	12	10	4	—	Deceased	2095
7	male	79	rAAA	25	O	0	11	3	—	Deceased	2132
8	male	52	rAAA	35	RF	0	7	3	12	Fully recovered, no hernia	1986
9	female	63	rAAA	LO			6	3	2	Fully recovered No hernia	1547

EVAR = endovascular aneurysm repair.
LO = left open.
rAAA = ruptured abdominal aortic aneurysm.
RF = respiratory failure.
Th-AAA = Thoraco-abdominal Aortic Aneurysm.
0 days = redo surgery the same day as initial surgery.
O = oliguria.

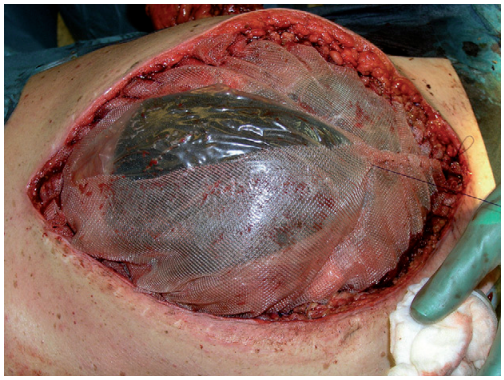

Figure 1 The mesh edges are approximated in a loose fashion over the plastic sheet covering the intestine, and then sutured together.

abdominal wall was closed with interrupted figure-of-eight-stitches using Vicryl® 2 (Ethicon GmbH, Norderstedt, Germany). The laparostomy and first dressing change are normally performed under sterile conditions in the operating room. The subsequent dressing changes, including mesh-adjustments, are done under general anaesthesia in the intensive care unit (ICU) with the assistance of a nurse. All patients were on a ventilator and connected to infusion pumps and monitoring devices, and did not have to be moved to the operating room for dressing changes.

Prophylaxis with a broad-spectrum antibiotic, normally a second or third-generation cephalosporin, was given until the closure.

IAP was measured at least 3 times a day, and was kept $<$15 mmHg to maintain the decompressive effect. No formal IAP measurement was done during closure, but the IAP was closely monitored in the ICU after each dressing change. In patients in whom bowel resection was necessary, the colostomy was placed as far away from the midline as possible.

Results

Patient characteristics and main results are given in Table 1. ACS was complicated by respiratory failure in six cases and oliguria in four cases, while laparostomy was performed in two cases because the abdominal wall could not be closed without undue tension. Prior to laparostomy, the median IAP was 25 mmHg (range: 12—40). Organ failure was reversed in all patients, with the exception of one who died 7 days after decompression due to irreversible multi-organ failure. Delayed primary closure of the fascia was successful in all remaining patients with a median time interval of 10.5 days (range: 6—19) after decompressive laparotomy. The median number of dressing changes was four (range: 2—7). We faced no problem with elevated IAP after the introduction of VAWC with mesh traction. One patient suffered from pancreatitis resulting in recurrent ACS, and a second decompression became necessary 11 days after the initial closure. Colon necrosis occurred in two cases; one with and one without ACS. They were both treated by sigmoid resection 2 days after the initial aneurysm repair. Intra-abdominal abscess formation, intestinal fistula or vascular graft infection were not observed. Fluid leakage was not a problem.

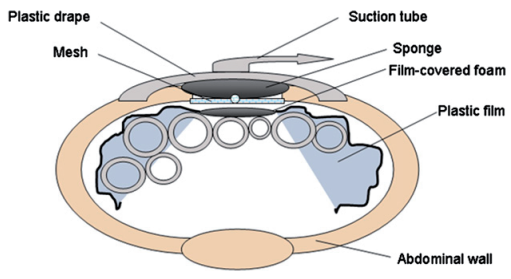

Figure 2 Schematic presentation of the technique.

One patient died 38 days after final closure and another after 50 days, due to heart and respiratory failure, respectively, but not due to ACS in itself.

The mean length of follow-up was 17 months (range: 2—36). The six surviving patients made a full recovery, but two small incisional hernias were seen.

The material costs for the VAWC and mesh treatment varied from 1547 to 3630 Euros for the individual patient.

Discussion

Several techniques have been described to treat an open abdomen. They range from loose packing of the abdominal wound to retention sutures and mesh techniques to approximate the fascia.[10—18] Only one small randomised trial comparing two different methods of TAC after trauma surgery has been reported.[21] They compared the use of mesh and vacuum-assisted closure. The application of mesh was compared to VAWC, and the results in the two groups were similar. However, only ~30% of the abdominal wounds could be closed by delayed primary closure in this study.[21] This is in contrast to our results where all cases were successfully closed. We have a relatively short median time interval to closure of 10.5 days, while other authors have reported a median time of 32 days before the abdominal wall could be closed.[18] Difference in the patients' condition as well as degree of subsequent organ failure may partly explain this discrepancy. Furthermore, our series consisted of patients with only 1A open abdomens without any rigidity or fixity at the time of initial surgery.

Dressings were changed under sterile conditions in the ICU in all but the first and last dressing change. The mesh application and the final closure were always performed in the operating room. Hence, most of the dressing changes were done during regular day-time working hours as this facilitates dissemination of knowledge of the technique and its use to staff members. We feel that the use of VAWC and mesh traction has significantly facilitated the postoperative care of patients with laparostomy in our institution. In our earlier experience with loose packing of the open abdomen, fluid leakage and frequent dressing changes was common. By using the V.A.C. therapy and applying the drape to a dry surface, the problem of fluid leakage has been eliminated. In our study, no patient developed

intestinal fistula, compared to 2.9% in a recent review by van Hensbroek 2008.[22] We used a lower negative pressure than others, 75 mmHg compared to 125 mmHg, but the importance of this with regard to the risk of fistula formation remains speculative. No patients developed an abscess, compared to a median of 2.6% of the patients reported by other investigators.[22] No vascular graft infection was observed, and this is in accordance with other reports.[23] Previously, laparostomy wounds were left open to heal by second intention and using split-skin grafting to cover the intestines. A large incisional hernia was likely to follow, and repair of this could be difficult.[24] To prevent lateralisation of the fascia during the treatment, we agree with Koss *et al*.[17] that a fascial traction device in addition to VAWC is needed to avoid excessive retraction of the fascia laterally which could make the final closure difficult. Two small incisional hernias were seen, but it is early to estimate the risk of incisional hernia following our current technique. We used Vicryl, which is a suture that absorbs rapidly, to close the fascia. Israelsson et al.[25] recommend a permanent suture or a slowly absorbable suture to prevent incisional hernias. A recently published RCT by Seiler *et al*.[26] did not confirm this. By the time of delayed primary closure, we found that the fascial edges, sometimes, were quite ragged, and large bites of the fascia had to be included in the suture. To avoid damage of the fascial edges by the mesh-sutures, Miller et al. have suggested that, after covering the intestines by a plastic sheet, only a sponge should be placed between the plastic and the outer abdominal wall before vacuum is applied.[14] The two cases of colonic necrosis were probably related to the initial trauma of rAAA and ACS and not to the closing device because they appeared prior to mesh placement.[27] Whenever left colon resection is necessary, we would recommend placing the stoma as far from the midline incision as possible to avoid adhesions between the intestine and abdominal wall that are too close to the fascial edges. The V.A.C. therapy and mesh traction closure method is a practical wound closure system for the treatment of an open abdomen, and has made this condition easier to treat. However, a longer follow-up period and systematic studies of the different steps of the procedure are necessary to evaluate the effect of this approach on overall mortality and morbidity after repair for rAAA with ACS.

Conclusion

Our study indicates that urgent laparostomy is an effective treatment for ACS, and that closing of the open abdomen with a combination of fascial traction and VAWC is feasible in the clinical routine. However, further multi-centre randomised trials are warranted to determine the optimal treatment modality for patients with open abdomen after aortic repair.

Study Limitations

This is a small group of patients treated with open abdomen in a single institution. Other limitations are that there was no randomisation, no control group and a rather short follow-up period.

Conflict of Interest/Funding

None declared.

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Paper II

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Paper III

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Critical Care

RESEARCH Open Access

Bedside dressing changes for open abdomen in the intensive care unit is safe and time and staff efficient

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Abstract

Background: Patients with an open abdomen (OA) treated with temporary abdominal closure (TAC) need multiple surgical procedures throughout the hospital stay with repeated changes of the vacuum-assisted closure device (VAC changes). The aim of this study was to examine if using the intensive care unit (ICU) for dressing changes in OA patients was safe regarding bloodstream infections (BSI) and survival. Secondary aims were to evaluate saved time, personnel, and costs.

Methods: All patients treated with OA in the ICU from October 2006 to June 2014 were included. Data were retrospectively obtained from registered procedure codes, clinical and administrative patients' records and the OR, ICU, anesthesia and microbiology databases. Outcomes were 30-, 60- and 90-day survival, BSI, time used and saved personnel costs.

Results: A total of 113 patients underwent 960 surgical procedures including 443 VAC changes as a single procedure, of which 165 (37 %) were performed in the ICU. Nine patients died before the first scheduled dressing change and six patients were closed at the first scheduled surgery after established OA, leaving 98 patients for further analysis. The mean duration for the surgical team performing a VAC change in the ICU was 63.4 (60.4–66.4) minutes and in the OR 98.2 (94.6–101.8) minutes ($p < 0.001$). The mean duration for the anesthesia team in the OR was 115.5 minutes, while this team was not used in the ICU. Personnel costs were reduced by €682 per procedure when using the ICU. Forty-two patients had all the VAC changes done in the OR (VAC-OR), 22 in the ICU (VAC-ICU) and 34 in both OR and ICU (VAC-OR/ICU). BSI was diagnosed in eight (19 %) of the VAC-OR patients, seven (32 %) of the VAC-ICU and eight (24 %) of the VAC-OR/ICU ($p = 0.509$). Thirty-five patients (83 %) survived 30 days in the VAC-OR group, 17 in the VAC-ICU group (77 %) and 28 (82 %) in the VAC-OR/ICU group ($p = 0.844$).

Conclusions: VAC change for OA in the ICU saved time for the OR team and the anesthesia team compared to using the OR, and it reduced personnel costs. Importantly, the use of ICU for OA dressing change seemed to be as safe as using the OR.

Keywords: Abdominal compartment syndrome, Open abdomen, Dressing changes, Infections, Intensive care, Resources, Health economy

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Background

Treatment of patients with open abdomen (OA) is demanding for the intensive care unit (ICU) and the hospital. OA patients require long ICU and hospital stays with repeated intra-hospital transport to the operating room (OR) for dressing changes and other surgical procedures related to the OA and/or the primary disease [1–5].

Although the well-equipped OR is the ideal location for surgery, several studies have reported that procedures like diagnostic laparoscopy, percutaneous tracheostomy, inferior vena cava filter placement, and percutaneous gastrostomy placement can be safely performed in the ICU [6–9]. Moreover, surgery done outside the OR for trauma care is also reported to be feasible [10–14]. Critical incidents occurring during intra-hospital transportation of ICU patients have been reported, and using the ICU as an OR can eliminate this problem [15, 16].

The feasibility of using the ICU as the location for planned dressing changes for OA has been demonstrated [17, 18]. The availability of OR time may be limited and planned procedures are often delayed. One potential benefit of performing dressing changes in the ICU is that it can be done during office hours, with more dedicated surgeons present, and without interfering with more urgent emergency surgery needing a fully equipped OR. Poorer outcomes of surgical and ICU treatment performed outside office hours are reported, e.g., increased mortality after treatment for ruptured aortic aneurysm [19], increased risk for anastomotic leakage of colorectal anastomosis [20], and in patients with acute traumatic coagulopathy after-hours care was associated with worse outcomes [21]. Thus, OA procedures performed in the ICU might benefit from the procedures being performed during the day shift. No previous studies have compared OA dressing changes performed in the OR versus the ICU.

According to the EPIC II study, approximately 12 % of the ICU patients die [22] and bloodstream infection (BSI) is a contributor to death [23]. Vidal et al. reported that 21 % of ICU patients with intra-abdominal hypertension had a BSI [24], and in a study of patients with OA due to abdominal compartment syndrome (ACS) following pancreatitis, 66 % had a BSI [25]. In trauma patients with ACS, BSI was reported in 26–36 % of the cases [26, 27]. The ICU is often a contaminated environment, and it may be that the risk for BSI is increased by performing the surgery in the ICU.

The primary aims of this study were to assess if using the ICU for planned OA dressing is safe for ICU patients with regard to 30-, 60- and 90-day survival and incidence of BSI compared to using the OR. Secondary aims were to evaluate if this approach saved time, personnel resources, and reduced costs.

Methods

The study was performed in the ten-bed mixed-case ICU at St. Olavs University Hospital, Trondheim, Norway; a tertiary referral center for a population of 710,000 inhabitants. All patients treated in the ICU with OA between October 2006 and June 2014 were identified through the hospital's patient administrative system and several departments' specific prospective registries. Searches were also performed in the surgical procedures registry, ICU registry, anesthesia registry and in patients' records to identify the exact surgical procedures performed on this cohort. The study was approved by the Regional Ethics Committee Mid-Norway, reference 2014/957. All living patients gave their written informed consent while the regional ethics committee waived obtaining informed consent from relatives of deceased patients.

The location of where the surgery took place (ICU, OR), type of surgical procedure, hospital length of stay, ICU length of stay, gender, age, simplified acute physiology score (SAPS II), reason for OA treatment, respirator time, and survival were obtained from patients' records, the anesthesia registry and the ICU registry. Data on BSI were obtained from the microbiological registry. Surgical reports obtained from the patients' records were reviewed to identify procedures involving only vacuum-assisted closure (VAC) change for OA, a procedure which was performed with a similar surgical technique in the OR and the ICU. The cohort was divided in three groups based on the location of the VAC change. The VAC-OR group having all their dressing changes done in the OR; the VAC-ICU group having all their dressing changes done in the ICU; and the VAC-OR/ICU group having dressing changes done both in the OR and ICU in no systematic order. Survival and incidence of BSI were compared between groups.

For all patients, the time used for each VAC change was obtained from the surgical and anesthesia registries. The following time-related parameters were extracted: time used by the surgical team to prepare the patient before surgery; time for the surgical procedure ("knife time"); time used by the surgical team after surgery; and total surgical team time. Anesthesia time was defined as the time used by the anesthesia team handling the patient before, during, and after surgery, including the time used to transport the patient between the ICU and the OR.

Office hours were defined as surgery taking place between 8 am and 5 pm, Monday to Friday. The time between 5 pm and 8 am and Saturdays and Sundays were defined as out of office hours.

Data on SAPS II and ICU treatment with respiratory support, dialysis, and length of stay (LOS) were obtained from the ICU registry. Date and cause of death were collected from the patients' records. BSI was registered at the date the microbe was first identified in the blood

culture. Only positive blood cultures found after initiating the OA were used in the analyses. Blood samples were not drawn as part of a scheduled plan or at a predefined time after operations, but on clinical indications.

Dressing changes (DC) for the OA included negative pressure wound therapy (NPWT) and rectus fascial traction with a mesh [4, 18, 28]. After removal of the old dressing, a new plastic film was placed between the viscera and the abdominal wall to prevent formation of adhesions to the abdominal wall and to protect the intestines from the foam. An outer sponge secured by a plastic drape covered the abdominal defect. Vacuum was applied at a continuous negative pressure of 50 to 125 mm Hg, both V.A.C.® therapy and ABThera™ (KCI, San Antonio, TX, USA) were used. According to the standardized protocol, the dressing was removed and the abdominal wall closed provided this could be done without tension after 2 or 3 days. If closing was not possible, a new dressing change was performed. The OA protocol requires change of dressing every second or third day, earlier if necessary due to alteration of the patient's condition. No protocol existed for where the dressing changes should take place, and the decision of using either the OR or ICU was done by the surgical team in care of the patient based on their preferences.

When surgery was performed in the OR, a fully equipped OR was used involving two surgeons, one surgical nurse, one scrub nurse, one anesthetist and two nurse anesthetists, engaging a total number of seven health workers. After use, the OR was cleaned and prepared in order for the next procedure by two cleaners taking 30 minutes each. The changes were done with either general or regional anesthesia. VAC change at ICU was performed with a team of two surgeons, one surgical nurse and one scrub nurse in addition to the ICU nurse. The already intubated patient was given opioids, sedatives and muscle relaxants as ordered by the ICU physician, administered by the ICU nurse. All personnel in the room used a surgical cap and mask; those in the field scrubbed in and used sterile operating garments and gloves (Fig. 1). Only a small surgical kit with the necessary equipment for completing the VAC change was used. Admittance to the operating field was restricted, and the door, if any, was closed and guarded. No equipment for bowel resection/major surgery was present, but if necessary, it could be available in a few minutes, or if in need for more extensive surgery, a temporary abdominal closure (TAC) was performed and the patient transferred to an ordinary OR for completion of the surgery.

All emergency surgery is prioritized to OR according to a traffic light coding system, modified from Leppäniemi et al. [29]. Patients were classified as red, yellow, and green, which correspond to a maximum of 6, 24, and 72 hours delay before surgery. Initial treatment for ACS is defined as red and VAC change for the OA is defined as yellow.

The personnel costs were estimated from average wages with social benefits for the year of 2014 for each profession involved. The costs for 1 hour with an anesthetist and a surgeon is €98 each, for a scrub nurse and a nurse anesthetist €65 each and for the cleaners €40 each. The mean elapsed time for each of the personnel groups involved in the procedure was used for the calculation.

Statistics

Continuous data are presented as median with range or mean with 95 % confidence interval (CI). Between-group comparisons of continuous variables were performed

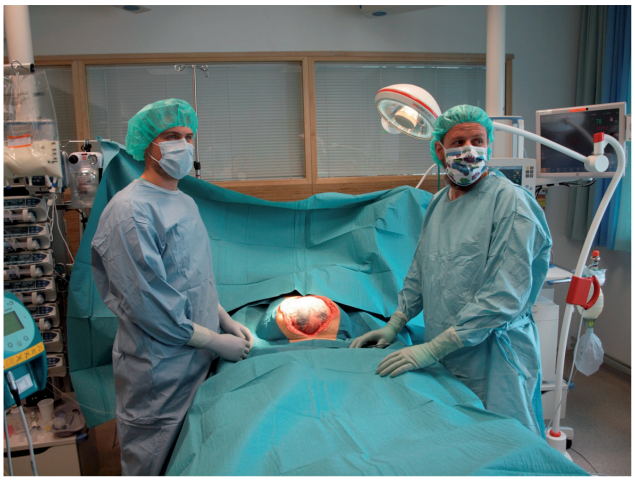

Fig. 1 Performing the dressing change in the intensive care unit (ICU) in a sterile fashion with a portable operating light

with Mann-Whitney test (nonparametric) or Student's t test and one-way analysis of variance (ANOVA) (parametric), and if extreme skewness transformation was used. Statistical comparisons of the duration of the VAC change, including total time, surgical time, and duration of anesthesia in the ICU compared to the OR were performed with an independent t test. Categorical variables were compared using Pearson chi-square test or Fisher's exact test. Cox regression analysis was used to perform adjusted survival analysis. The statistical significance level was set to $p < 0.05$, two-tailed. Data were analyzed in Excel, Windows 2010 (Microsoft Corp., Redmond, WA, USA) and IBM SPSS software, version 21 (IBM Corp., Armonk, NY, USA).

Results

All 113 patients treated with OA from the Departments of Surgery (n = 95), Trauma (n = 9), Internal Medicine (n = 5), and Gynaecology and Obstetrics (n = 4) were included. Indications for OA were abdominal compartment syndrome (ACS) (n = 53), abdomen could not be closed due to intra-abdominal swelling (loss of domain) (n = 27), abdominal contamination/second look (n = 19), necrotizing fasciitis (n = 7), hemorrhage packing (n = 4), and full thickness dehiscence (n = 3). A total of 960 surgical procedures were performed, of which 443 were dressing changes and 109 were dressing changes combined with other procedures like mesh placement to complete the TAC (n = 34), and resection of ischemic bowel and gall bladder (n = 19). After the index operation for OA, nine patients died before the first scheduled DC and six patients were closed at the first scheduled surgery after OA was established, leaving 98 patients for further analysis.

These 98 patients were in need of 552 VAC changes after the index operation for open abdomen, with a median of four (range 1–26) procedures. The number of VAC changes being the only procedure was 443 with 278 done in the OR and 165 done in the ICU, among which 413 were scheduled and 30 were unplanned. Of the unplanned, 24 were done in the OR and six in the ICU. All changes at the ICU were completed as planned, except in one patient who was transferred to the OR due to an unexpected finding of necrotizing pancreatitis which needed necrosis removal. Forty-two patients had all VAC changes done at the OR (VAC-OR), 22 all in the ICU (VAC-ICU), and 34 patients had VAC change done both in the OR and ICU (VAC-OR/ICU). There were no differences in age, SAPS II, sex and ACS as reason for OA between the groups, but renal replacement therapy (RRT) was more frequent in the VAC-ICU and VAC-ICU/OR group, 32 % and 35 %, respectively, compared to 12 % in the VAC-OR group ($p = 0.0206$) (Table 1). All patients received mechanical ventilator support, and most of them until their abdomens were closed. Nineteen of the patients were re-intubated for a median of three (1–19) procedures before closure of the open abdomen. Patients in the VAC-

Table 1 Patients characteristics

	All n = 98	VAC-OR n = 42	VAC-ICU n = 22	VAC-OR/ICU n = 34	p
Number of men (%)	73 (72 %)	27 (64 %)	17 (77 %)	28 (82 %)	0.100[a]
Age, median (range)	64 (20–88)	58.5 (22–88)	70.5 (24–82)	65.5 (20–82)	0.093[b]
Reason for OA, n (%)					
ACS	46 (47 %)	18 (43 %)	10 (46 %)	18 (53 %)	0.681[a]
Intraabdominal swelling	25 (26 %)	9 (21 %)	9 (41 %)	7 (21 %)	0.198[a]
Abdominal contamination/second look	14 (14 %)	7 (17 %)	3 (14 %)	4 (12 %)	0.931[a]
Other	13 (13 %)	8 (19 %)	0 (0 %)	5 (15 %)	0.077[a]
Primary diagnosis, n (%)					
Vascular	45 (46 %)	14 (33 %)	14 (64 %)	17 (53 %)	0.058[a]
Gastrointestinal	31 (43 %)	18 (43 %)	4 (18 %)	9 (27 %)	0.094[a]
Trauma	9 (8 %)	3 (7 %)	1 (5 %)	5 (15 %)	0.481[a]
Urological	6 (6 %)	4 (10 %)	0	2 (6 %)	0.421[a]
Internal medicine	4 (4 %)	0	3 (14 %)	2 (3 %)	0.038[a]
Gynecological	3 (3 %)	3 (7 %)	0	0	0.240[a]
Clinical characteristics					
SAPS II, median (range)	43.1 (40.3–45.8)	40.2 (36.0–44.3)	46.6 (41.0–52.6)	44.3 (39.5–49.0)	0.158[b]
Dialysis, n (%)	24 (24 %)	5 (12 %)	7 (32 %)	12 (35 %)	0.0206[a]

VAC-OR all dressing changes in the operating room, *VAC-ICU* all dressing changes in the intensive care unit, *VAC-OR/ICU* dressing changes in the operating room and intensive care unit, *OR* operating room, *ICU* intensive care unit, *OA* open abdomen, *ACS* abdominal compartment syndrome, *SAPS II* simplified acute physiology score II

[a]Fisher exact test; [b]one-way ANOVA

OR group had fewer days on respirator compared to the VAC-ICU group, 11.8 vs. 20.4 days ($p = 0.007$), respectively (Table 3). Similarly, the ICU LOS was 15 days for the VAC-OR group compared to 21.5 days in the VAC-ICU group ($p = 0.787$). However, LOS in the hospital was 35.5 days in the VAC-OR group and 34.5 days in the VAC-ICU group.

The mean total time the surgical team spent on VAC change was 63.4 (60.4–66.4) minutes when using the ICU compared to 98.2 (94.6–101.8) minutes in the OR, with a difference of 33.8 (27.0–40.6) ($p < 0.001$). Time used for the anesthesia team in the OR was 115.5 (111.0–120.0) minutes (Table 2). The anesthesia team was not involved in VAC changes done in the ICU, and therefore, the time saved for the anesthesia team for three persons equals the total time used in the OR ($115.5 \times 3 = 346.5$ minutes).

For a patient having the dressing change performed in the OR, the personnel costs for all employees were €908, compared to €226 when the ICU was used, thus personnel costs were reduced by €682 for each dressing change.

For VAC changes in the ICU, 122 (74 %) were performed during weekdays, similar to the 210 (76 %) procedures performed during the weekdays in the OR ($p = 0.734$). The dressing changes were performed during office hours in 93 out of 165 (56 %) ICU procedures, similar to 157 out of 278 (56 %) OR procedures ($p = 1$).

BSI was detected in 33 (29 %) patients during the hospital stay; in ten patients prior to OA treatment and in 23 patients during or after OA treatment (Table 3) with a median of 13 (range 1–96) days after established OA. No multidrug-resistant strains were found. The median time from OA being established to intestinal species being detected in the blood was 15 (2–96) days, for staphylococcal infection it was 19 (4–81) days, and for candida 8 (3–13) days. In the 70 patients surviving 90 days, 20 patients had a BSI, compared to 13 in the 28 patients not surviving 90 days ($p = 0.103$). In the 42 patients having their VAC changes done in the OR, eight patients (19 %) were diagnosed with a BSI during or after OA treatment compared with seven of 22 (32 %) patients in the VAC-ICU group, and eight of 34 (24 %) in the VAC-OR/ICU group ($p = 0.509$).

Eighty patients (82 %) survived 30 days. Thirty-five patients (83 %) survived in the VAC-OR group, 17 (77 %) in the VAC-ICU group and 28 (82 %) in the VAC-OR/ICU group ($p = 0.844$). The 60- and 90-day survival rates were 75 % and 71 % respectively, with no difference between the subgroups (Table 3).

In a multivariate analysis adjusting for age, sex, SAPS II, dialysis and location of dressing change, only high age and need of renal replacement therapy increased the hazard ratio (HR) of death with 1.04 (95 % CI: 1.001–1.081 %, $p = 0.047$) and 2.47 (95 % CI 1.08–5.65, $p = 0.032$), respectively (Fig. 2).

Discussion

This study demonstrated that VAC change on patients with open abdomen (OA) can be done safely outside the operating room. Utilizing the ICU as a surgical suite for performing repeated changes of the OA did neither influence 30-, 60- and 90-day survival nor incidence of BSI. Additionally, the study showed that performing the dressing change in the ICU reduced costs and time spent on the surgical procedure, and it made the anesthesia team superfluous.

High age and renal replacement therapy were associated with an adverse outcome after open abdomen treatment [30]. Other studies have reported survival after OA therapy in the range of 50–72 %. Thus, the survival of patients with OA in the present study was similar to previous reports [2, 4, 5, 17, 31–33]. The VAC-ICU patients stayed longer at the ICU compared to the VAC-OR group, most likely due to more severe pulmonary and renal failure, however, the length of stay in the hospital and survival were similar.

Despite the risk of a more contaminated ICU environment for the patients with DC performed in the ICU, they were not at a higher risk of BSI during and after the OA treatment. BSI affected almost one third of the study population, and in the patients not surviving 90 days almost half had BSI. This observation is in line with previous studies including patients with abdominal hypertension, ACS or OA [24, 26, 27], and eight of the 23 BSIs were due to staphylococcal infection, and thus most likely they were caused by intravenous catheters and not by contamination from the OA.

To our knowledge, this is the first study comparing time spent for VAC change on OA for two surgical

Table 2 Time used for open abdomen dressing changes in the intensive care unit (ICU) and operating room (OR)

	ICU n = 165	OR n = 278	Time difference	*p*
Preoperative time (min)	26.4 (24.4–28.3)	45.1 (43.1–47.0)	18.7 (15.7–21.7)	<0.0001[a]
Surgical time (min)	29.8 (27.9–31.7)	35.2 (33.2–37.2)	5.5 (2.5–8.5)	<0.0001[a]
Postoperative time (min)	7.2 (6.6–7.8)	17.9 (16.5–19.3)	10.7 (9.2–12.2)	<0.0001[a]
OR/sum time (min)	63.4 (60.4–66.4)	98.2 (94.6–101.8)	33.8 (27.0–40.6)	<0.0001[a]
Anesthesia time (min)	NA	115.5 (111.0–120.0)	NA	NA

Values in minutes with mean and 95 % confidence interval.
NA not applicable
[a]Student's *t* test

Table 3 Duration of open abdomen (OA), respirator and intensive care unit (ICU) treatment, number and type of bloodstream infection (BSI) and survival

	All (n = 98)	VAC-OR (n = 42)	VAC-ICU (n = 22)	VAC-OR/ICU (n = 34)	*P*
Days with OA (median, range)	13 (1–143)	10.5 (1–88)	12.5 (2–22)	18.5 (2–143)	0.002[b]
Days on respirator (median, range)	15.5 (1–62)	11.8 (1–62)	20.4 (9–49)	16.1 (1–48)	0.007[b]
LOS ICU, days (median, range)	18 (1–89)	15 (1–70)	21.5 (7–67)	17 (8–89)	0.078[b]
LOS total hospital, days (median, range)	35.5 (3–246)	35.5 (3–215)	34.5 (10–143)	36 (10–246)	0.787[b]
Bloodstream infection (n, %)	23 (23 %)	8 (19 %)	7 (32 %)	8 (24 %)	0.509[a]
Escheria coli		3	1	0	
Enterococci		0	1	4	
Enterobacter		1	0	0	
Staphylococci		3	3	2	
Candida		0	2	1	
Bacteroides		1	0	0	
Beta-hemolytic streptococci g. A		0	0	1	
30-day survival (n, %)	80 (82 %)	35 (83 %)	17 (77 %)	28 (82 %)	0.844[a]
60-day survival (n, %)	73 (75 %)	34 (81 %)	16 (73 %)	23 (68 %)	0.384[a]
90-day survival (n, %)	70 (71 %)	34 (81 %)	15 (68 %)	21 (62 %)	0.172[a]

VAC-OR all dressing changes in the operating room, *VAC-ICU* all dressing changes in the intensive care unit, *VAC-OR/ICU* dressing changes in the operating room and intensive care unit, *OR* operating room, *ICU* intensive care unit, *OA* open abdomen, *LOS* length of stay
[a]Fisher exact test; [b]one-way ANOVA

locations; the OR and the ICU. The present results demonstrate a significant reduction of the time spent on preparing the OA patient for surgery when the VAC changes were performed at the ICU. The excess time used before surgery at the OR did not only relate to transportation from the ICU to the OR, but also to the time used to move the patients from the bed to the OR table, and also the time used when more personnel groups are involved. One example of the latter is the use of special assistants to lift and position the patients at the OR table at our hospital. The difference in time used for the procedure could be addressed by for instance preparing a simplified surgical equipment package similar to the one used in the ICU instead of the more advanced surgical equipment package used in the OR. The surprising finding that surgical time (knife time) differed in favor of having the dressing changed in the ICU was not due to more advanced surgery performed at the OR, as similar procedures were compared. Furthermore, the same surgeons and nurses were involved in the procedures at both locations. The time difference may partly be explained by the fact that all surgical equipment was immediately available in a prepared surgical kit in the ICU room. The time used after the procedure was finished was also significantly shorter in the ICU group, due to no need of patient transportation and less use of surgical equipment. Importantly, the anesthesia team was not involved in the treatment performed in the ICU, making an entire anesthesia team available for other activities. Altogether, the use of the ICU saved considerable personnel costs for the hospital.

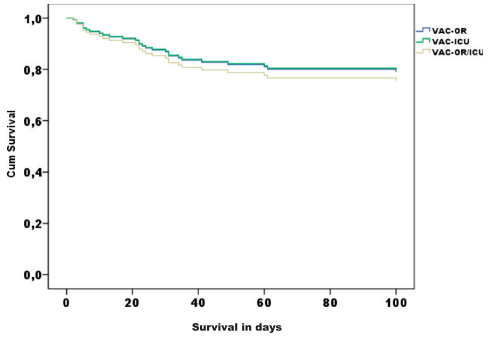

Fig. 2 Cox regression analyses for survival dependent on where dressing change where performed adjusted for age, sex, renal replacement therapy, simplified acute physiology score II (SAPS II) and incidence of bloodstream infection (BSI). *VAC-ICU* all dressing changes in the intensive care unit, *VAC-OR* all dressing changes in the operating room, *VAC-OR/ICU* dressing changes in the operating room and intensive care unit

Only one patient who had his dressing changed at the ICU needed to be transferred to the OR for completion of surgery. In all other cases, the dressing change was completed in the ICU. This supports a practice where OA dressing changes can be done in the ICU as long as no additional procedures are planned.

The organization of emergency surgery is important, as the availability of surgical teams, anesthesia teams

and ORs are limited resources. VAC changes for OA can either delay emergency surgeries or necessitate VAC change for OA to be done after office hours. Moreover, this group of patients is usually complex, needing ventilator support and multiple infusions including vasoactive drugs. The unstable patients is exposed to a substantial risk when being transferred out of the ICU to the OR, which should be avoided if not clearly indicated [15, 16, 34]. Of course patients need to be monitored during the DC, and most patients need additional analgesics, sedatives and muscle relaxants during the procedure, but this can be administered by ICU personnel caring for the patient in the ICU.

We recognize that this study has limitations. This was a retrospective study and there was no predefined protocol to decide where to perform the DCs. Therefore, a bias may have been introduced as the surgical team performing the DC chose the location based on their preference and/or the patient's condition, introducing multiple possible confounding factors. For instance, more patients in the ICU and ICU/OR groups received dialysis compared with the OR group. This may reflect that dressing changes in those patients were done in the ICU in order not to interrupt continuous renal placement therapy. Furthermore, the blood cultures were obtained as indicated and not routinely collected, and other infections such as local infections in the OA were not included in the data material. Although the current study was relatively large compared to other publications, the numbers are still limited for each subgroup, and therefore, due to the risk of type II statistical errors, the results should be interpreted with caution. Finally, this is a single-center study, and all findings may not be generalizable to other organizations. Hence, larger cohorts, preferably multicenter studies, with standardized assessments of complications are needed in order to conclude on outcomes related to location for dressing change for OA treatment.

Conclusions

In this study on 98 patients, VAC changes for open abdomen in the ICU were cost and time efficient for the surgical and anesthesia departments, and seemed to be safe. Further studies on larger patient cohorts, preferably with a prospective multicenter design, are warranted.

Key messages

- Performing VAC changes for open abdomen in the ICU is cost, time, and staff efficient.

Abbreviations

ACS, abdominal compartment syndrome; ANOVA, analysis of variance; BSI, bloodstream infection; CI, confidence interval; DC, dressing change; HR, hazard ratio; ICU, intensive care unit; LOS, length of stay; NPWT, negative pressure wound therapy; OA, open abdomen; OR, operating room; RRT, renal replacement therapy; SAPS II, simplified acute physiology score II; TAC, temporary abdominal closure; VAC, vacuum-assisted closure

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Authors' contributions

AS planned the study, gathered the data, performed the statistical analyses, and wrote the manuscript. SF gathered data from the anesthesia registry, interpreted the data, and performed critical review of the statistics and the manuscript. SM gathered data from the intensive care registry, interpreted the data, performed the critical review of statistical analyses and the manuscript. PK, TD and MB interpreted the data, and performed the critical review of the manuscript. AW oversaw the entire process, interpreted the analyses and contributed to the writing of the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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