Evaluation of the Components Separation Method for treatment of patients with large abdominal wall defects

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Evaluatie van de Componenten Separatie Methode voor de behandeling van patiënten met grote buikwanddefecten

(met een samenvatting in het Nederlands)

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Chapter 1 - Introduction and outline of this thesis

Introduction and outline of this thesis

An incisional hernia is defined as a postoperative protrusion of abdominal viscera through a defect in the abdominal wall, into the subcutaneous tissue, enveloped in a serous sac which is in continuity with the peritoneum.[1] It is a well known complication after abdominal surgery occurring in 11 % to 18.7 % of patients, within 10 years after laparotomy.[2,3] Occurrence of an incisional hernia can be related to an error in surgical technique but is generally a multifactorial situation, often the result of deterioration of the patient's condition, especially local wound disturbances e.g. postoperative wound infection.[4] Long term follow up shows that 40 % of patients with an incisional hernia eventually become symptomatic with incarceration and strangulation requiring emergency surgery as worst case presentations in a small amount of patients.[5,6] Less alarming symptoms are recurrent intestinal obstruction, atrophic apical- or intertrigous peripheral skin coverage of the hernial sac, chronic (back) pain or cosmetic complaints.

In longstanding hernia, a considerable amount of the abdominal contents will loose its "abdominal domain" due to abdominal wall weakness and lateral retraction of the muscles. Surgical repair of large abdominal wall defects must be considered a major and difficult procedure. Patients are often obese, in poor general condition and of older age.[6] Consequently, morbidity of surgery is high and long term results are poor with recurrence rates varying from 32 – 63 % after 10 years of follow-up.[7,8] The recurrence rate after surgical treatment of an incisional hernia is often underestimated because most studies are retrospective and are lacking long-term follow-up.

A wide spectrum of modalities has been described for the treatment of large abdominal wall defects but up till now there is no consensus on the optimal treatment for this clinical condition. Treatment options can be divided into closing- and bridging techniques. Closing techniques pursue re-approximation of the fascial edges to re-establish the initial anatomic situation, while a bridging technique connects these fascial edges by using a non physiologic compound, replacing the abdominal wall at the muscular defect. Closing a large abdominal wall defect by means of a (modified) Mayo technique (open suture repair) has a proven overall poor outcome and is therefore abandoned.[9] An abdominal wall defect can effectively be closed after performing relaxing incisions in the oblique abdominal muscles, if necessary with an additional augmentation technique (prosthetic mesh as an onlay or sublay). Bridging a defect can also be accomplished with prosthetic mesh or using myofascial rotation or transposition flaps.

Research mostly focuses on the size, composition, position and the correct moment to use prosthetic mesh for both bridging and augmentation procedures. Introduction of prosthetic material indeed lowered the recurrence rate of incisional hernia repair but was also accompanied by specific complications.[10,11] Chronic pain, deep wound infection, seroma formation, enterocutaneous fistulation, shrinkage of the mesh with possible recurrence (in case of inadequate overlap of the edges) are unfortunately well known complications.

Despite these drawbacks, mesh repair seems the easiest and therefore often preferred and generally applicable procedure. This is probably the reason why non-mesh repair has become less popular during the last decades. In 1990 Oscar Ramirez[12] published his preliminary results of a novel non-mesh surgical technique for closure of large abdominal wall defects. He described good results by using the so called Components Separation Method (CSM): a non-mesh functional repair in which the external and internal oblique abdominal muscles are separated after exposure through a midline laparotomy. By exclusive incision of the external aponeurosis, a separation of the external and internal oblique muscles can be realised as far as the posterior axillairy line. This will result in an impressive medial translation of the rectus abdominus, still connected to the internal oblique and transverse oblique muscle. As a consequence, large abdominal wall defects can generally be closed primarily with this tension-relaxing procedure without transposition of muscular flaps or the use of prosthetic mesh, while restoring a circumferential coverage of the abdominal cavity.

The different studies that are described in this thesis were performed to find answers to the following questions:

- can the CSM really facilitate closure of impressive Abdominal Wall Defects (AWD)?
- what mechanism is responsible for this technique?

- what are the results of the CSM on the long term?
- is additional mesh augmentation of the CSM beneficial?
- can the CSM be used in contaminated situations?
- can we develop a reproducible method to determine the result of hernia closure, regarding tissue perfusion?
- what is the current position of the CSM in surgical repairs for AWD's?

The surgical technique of the Components Separation Method with possible pitfalls and additional recommendations, is described in **chapter 2**. Although Ramirez based his surgical technique on the results of anatomical studies, several questions remained unanswered and the responsible mechanism of this technique is not completely explained. We investigated the mechanical changes in the anatomy of the abdominal wall muscles in a standardized human cadaver model and tried to explain the mechanism behind the CSM (**chapter 3**).
In 1994 the Components Separation Method was introduced at the University Medical Centre Utrecht and three years later at the Jeroen Bosch Hospital 's-Hertogenbosch. Gradually we became more experienced with this non-mesh technique and it soon became our treatment of choice for patients with large abdominal wall defects after midline laparotomy. Although complications did occur we believe the CSM is a very reasonable option for symptomatic patients with this grotesque pathology. In **chapter 4** we describe the results of a retrospective study in 95 patients who were treated in a six year period with a median follow-up of 48 months.
One of the hazards of mesh repair is the risk of infectious complications, especially in case of intra-operative bacterial contamination. Application of prosthetic mesh in a contaminated wound will generally lead to deep wound infection. To emphasize the applicability of the CSM in contaminated situations we studied 26 of our patients in detail, in whom abdominal wall reconstruction under contaminated conditions was performed, with respect to wound related problems and recurrences and described our results in **chapter 5**. As mentioned before, many patients with large abdominal wall defects complain of back pain, forcing them to change their lifestyle or even to give up employment.[13] Correction of a large abdominal wall defect should therefore have a positive effect on these complaints and consequently on the quality of life.[14] Additionally, closure of a large abdominal wall defect with the CSM can theoretically

improve postoperative pulmonary function because abdominal breathing is restored and the containment capacity of the abdomen increased, allowing the abdominal content to regain it's domain without excessive restriction of the intrathoracic volume. As a pilot-study, we prospectively investigated the effects of the CSM on quality of life as well as on pulmonary- and abdominal wall muscle function in 6 patients, using Short Form-36, dynamic lung function (spirometry) and abdominal muscle functions (leg raises and crawl-ups) both preoperatively and 6 months after performing the CSM (**chapter 6**).

In general, two strategies exist for the treatment of abdominal wall defects that are not amenable to tensionless approximation of the natural tissues: bridging or closing the defect (after a tension-reducing technique). At present, no criteria exist on the amount of tension reduction which is required to allow succesfull re-approximation. As adequate perfusion is a prerequisite for any type of wound healing and wound related problems are often seen in case of raised Intra Abdominal Pressure (IAP) after laparotomy, sustained reduction of abdominal wall perfusion could theoretically be a good explanation for incisional hernia formation.

In **chapter 7** we investigated the relation between elevated intra-abdominal pressure and tissue perfusion in the rectus muscles in a healthy patient population. By using a Lycox microcatheter probe within the rectus muscle, we tried to establish a reproducible method to determine the critical amount of tissue perfusion and subsequent muscle-tension in the future.

In **chapter 8,** available literature on different types of abdominoplasty for reconstruction of abdominal wall defects is reviewed as well as our own and others' results with tissue expansion. Finally our series of augmented closures of large abdominal wall defects is reported.

In **chapter 9** the results of our studies are summarized and future prospects are discussed.

Chapter 10 presents a Dutch translation of the summary.

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Chapter 2 - The Components Separation Method: technical aspects for surgery

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Submitted

Introduction

The Components Separation Method (CSM), an established technique for tension reduced primary closure of large abdominal wall defects using relaxing incisions, was first described in 1990 by Oscar Ramirez[1], a plastic surgeon from Johns Hopkins, Baltimore. Application of this technique enables closure of large ventral hernias without using either remote autologeous material such as musculofascial flaps, or synthetic (non) absorbable material, by means of primary closure of the linea alba after separation of the muscular components of the lateral abdominal wall.

Captivated by the concept, we applied this method at the University Medical Centre in Utrecht and the Jeroen Bosch Hospital in ‘s-Hertogenbosch (both in the Netherlands) from 1994 onwards. We gained experience but also became aware of the possible concomitant morbidity introduced by this procedure.[2] Its limited application throughout the world might be due to the fact that the first publication was in a plastic surgical journal and its specific indication in abdominal wall surgery. Therefore elaborating the technical aspects of the CSM and dealing with its possible hazards and pitfalls is indicated.

Potential benefits

In general, minimal invasive approaches are used frequently for hernia repair with good results. However, in most patients with massive and often multiple recurrent ventral hernias, the large amount of the abdominal content that permanently is positioned outside the abdominal wall (so called “loss of domain”) excludes a minimal invasive approach and they will therefore need an open reconstruction. For open reconstruction, the abdominal wall defect is either bridged with synthetic material or patients’ own tissue, or closed after tissue expansion or relaxing incisions. By applying the CSM, the abdominal midline can be reconstructed in a one-stage procedure, without the need of an additional musculofascial transfer (distant flaps) or the use of prosthetic material. This will re-establish the “abdominal domain” and restore the natural centre of gravity to a position where it initially was.

Additionally this technique might provide an alleged dynamic repair because of the reconstruction of circumferential functional muscular support. This may not only be beneficial for the healing process but we suppose that this will also promote the patient's mobility and subsequent well being. Earlier reports show that 10 additional pounds on the anterior abdomen adds 100 lbs (45 kg's) of extra strain on the vertebral disks of the lumbar spine by exaggerating the normal S-curve of the spine.[3] Intact anterior abdominal wall muscles and the ability to raise intra abdominal pressure are essential for spinal support. They can reduce the stress at the intervertebral joints, by controlling the tension on the lumbodorsal fascia.[4] This explains the frequent failure of orthopaedic spine surgery in patients with large abdominal wall defects, without re-etablishing the integrity of the muscular anterior abdominal wall (as compared to women in advanced pregnancy with diastasis of the rectus muscles). After recreating circumferential muscular integrity, resolution of back pain in patients with huge abdominal wall defects is therefore more likely.

Pre-operative planning and optimizing patients operability

Despite the increasing number of laparoscopic operations, the incidence of incisional hernias did not show any dramatic changes during the last decennia and still seems to be stabilized at 10 – 15 %.[5-8] Accordingly, patients with abdominal wall defects will still be regularly presented in a general surgeon's outpatient clinic.

Symptoms vary from simple asymptomatic awareness of “a bulge” with or without cosmetic complaints, repetitive periods of ileus, severe abdominal- and backpain, painfull incarceration of an abdominal mass, spectacular growth of the bulge resulting in critically endangered abdominal skin, persistent skin ulceration or enterocutaneous fistulation.[7,8] All features except the first, more or less require an operation. Ample patient information about possible risks in relation to the benefits of reconstruction should be provided before the decision to operate can be taken. Principally, all patients with large mid-line abdominal wall defects (> 5 cm in width and total defect size exceeding 50 cm^2) in combination with debilitating symptoms or local conditions urging intervention, are considered possible candidates for the CSM. Due to the extensiveness of surgery necessary, concomitant morbidity is frequently seen and for this reason we only perform the CSM in the forementioned patients. An important risk factor is obesity. Therefore, preoperative weight loss under dietician control is advised, but significant results will not always be obtained. Despite the long lasting and often frustrating attempts for weight loss, we emphasise on the importance in all cases of reducable incisional hernias covered with vital skin because symptoms, the indication for and results of surgery can be positively influenced.[9]

Clinically significant pulmonary complications frequently occur after any open abdominal surgery, especially after midline incisions.[10] Preoperative physiotherapy alone can be effective in reducing the risk for postoperative pulmonary problems in combination with early mobilisation. Furthermore, the addition of Deep Breathing and Coughing (DB&C) to an existing program of early mobilisation has recently shown to produce no additional benefit in a randomised trial.[11,12] But based on the fact that these patients underwent more or less their final, extensive attempt of abdominal wall reconstruction and therefore early mobilisation is prohibited for the first 5 days, we do use a program of postoperative DB&C and change of body position under physiotherapeutic surveillance.

As the Body Mass Index (BMI) in these patients quite often exceeds 30, physical examination is not very sensitive in finding and measuring a fascial defect. Therefore, in most symptomatic patients a CAT-scan is performed for diagnosing and exact measurement of a (recurrent) fascial defect and excluding additional (non clinical) herniations. Additionally, not only the amount of possible 'loss of domain' can be determined but the position and condition of the muscular components of the abdominal wall can also be evaluated, since the atrophic rectus muscles are often laterally retracted.

In a patient with an abdominal wall defect measuring more than 20 cm's in width (before excision of fascial edges!), with lateralized atrophic (or even absent) rectus muscles, closing of the defect is not very likely and bridging by using an abdominoplasty is one of the alternatives.[13] Remote musculofascial flaps can be harvested and applied with various results.[14-23] But necessary plastic surgical expertise during surgery can be anticipated by means of pre-operative CAT-scan examination.

Although we have shown that contamination present during the operation, does not exclude abdominal wall reconstruction, we always try to eliminate soft tissue infection and diminish the amount of contamination in order to create a stable, granulating wound.[24] More and more often this is attempted by vacuum therapy with good results.[25-28] Up to now there are no evidence based recommendations concerning vacuum assisted wound management. But even enterocutaneous fistula can be effectively treated and patients' comfort will benefit from this type of outpatient wound management.[25]

Operative procedure and pitfalls

After admittance of the patient, physiotherapeutic respiratory training is started in order to reduce the risk for pulmonary complications and bowel preparation is not routinely performed. In addition to general anesthesia, we apply postoperative epidural (or patient-controlled intravenous) analgesia, which has shown to be superior to on-demand delivery of opoïds in preventing postoperative pulmonary complications.[11] Thirty minutes before surgery, patients receive amoxicilline/clavulan acid 1200 mg intravenously for antibiotic prophylaxis. Patients are placed in supine position and complete ventral abdominal disinfection is performed. In case of an expected need for musculofascial flaps, both upper legs are also prepared.

We start the procedure by excision of the possible granulating defect or the secondary healed scar (Figure I). Access to the abdominal cavity is gained with much precaution and all previously implanted synthetic material that can be reached safely, is excised.

Figure I. Excision of fascial edges, remnants of previous mesh and enterocutaneous fistulation.

Complete adhesiolysis, at least off all attachments to the abdominal wall, is performed to create a maximally mobile abdominal wall with no fibrotic restraints. Then dissection in the subcutaneous space is started just ventral to the rectus sheath, in a lateral direction. During this process, the unilateral rectus muscle should be grasped with the other hand, localizing the lateral border of the rectus muscle, so allowing to determine the endpoint of this subcutaneous dissection. This dissection is routinely performed with diathermia. Care has to be taken in patients who had numerous laparotomies, especially in cases of former ostomies, that had dissection right above the rectus muscle. One should leave the skin and subcutaneous layer in tact and as thick as possible, trying to prevent skin necrosis. Endpoint of this dissection is about 1 – 2 centimeter lateral to the rectus muscle at the junction of rectus sheath and the aponeurosis of the external oblique muscle.

In selected cases when additional skin necrosis is expected, for example due to ostomies, an alternative approach can be performed. In stead of the lateral subcutaneous dissection just ventral to the rectus muscle, a skin incision is made directly above the junction rectus abdominis and external oblique muscles. The components separation can then take place through this lateral skin incisions, reducing the risk for skin necrosis to a minimum. At the end of the procedure, both lateral skin defects need to be covered with split skin grafts.

Than the actual relaxing incision is placed with a (new) scalpel, just lateral to the forementioned junction, in a semilunar shape, parallel to the lateral border of the rectus muscle (Figure II). The aponeurosis of the external oblique muscle is very thin at this level so care has to be taken not to incise the aponeurosis of the underlying internal oblique muscle as well.

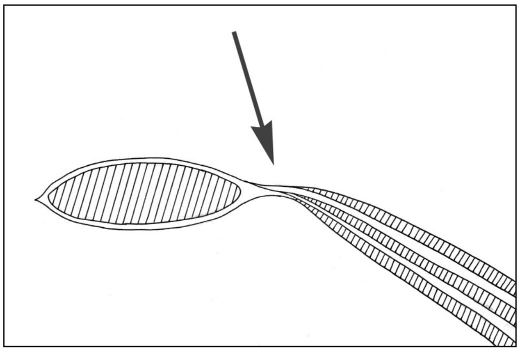

Figure II. Skin and subcutaneous tissue are mobilized and the aponeurosis of the external oblique muscle incised pararectally, about 1 cm lateral to the rectus muscle.

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Confirmation can be obtained visually from the direction of the exposed underlying muscle fibers. This incision is proceded in cranial direction, to a level above the costal margin, which is covered by the external oblique-, serratus anterior and the pectoralis muscle. Incision in caudal direction is limited by the proximity of the inguinal canal which should not be opened routinely.

After that, the external oblique muscle is fixed with graspers and lifted. Now the actual separation of the external and internal oblique muscle is started (Figure III). As nerves and vessels run between the internal- and transverse oblique muscles, the beforementioned space is nearly avascular. The loose connective tissue can be dissected bluntly in a lateral direction to the level of the posterior axillary line. Small sensory branches may theoretically come across in this plane but are only visualized (and spared) incidentally. Up till now, not a single patient has been aware of hypoesthesia of the overlying skin. The more lateral dissection progresses, small bleedings can occur and are best treated by direct gauze tamponade. The large wound surface in this plane is probably responsible for possible seroma and haematoma formation.

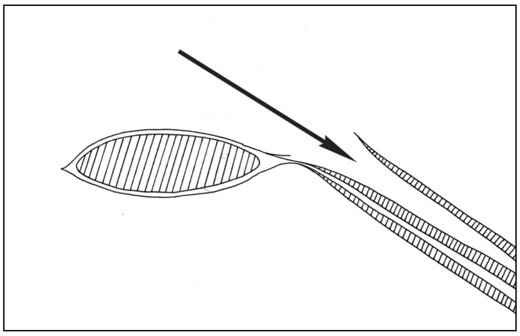

Figure III. The external and internal oblique muscles can be separated by blunt dissection.

The second step of the CSM is separating the posterior rectus sheath from rectus abdominis muscle. One centimeter more lateral to its medial border, an incision along the back side of the rectus abdominis muscle, in the posterior rectus sheath from subxiphoidal to the arcuate line, is performed. Lateral dissection in this plane is often easy and continued to the level of the epigastric vessels, avoiding damage to these vital structures.[29] The subxiphoidal part of this dissection requires proceeding high up underneath the ribs and should include the posterior lamina of the xiphoid process and the medial insertion of the posterior rectus sheath. Preparation of this retroxiphoidal space (fatty triangle), is especially important in case of mesh augmentation, when retromuscular, prefascial placement of synthetic material with sufficient overlap (5 cm) is essential.[30,31]

At this moment the "neo" linea alba, which can be a very broad fibrotic plate harbouring pieces of non resorbable mesh or protruding bowel, is excised.. This is continued laterally until healthy rectus muscle fibres are exposed; a prerequisite for adequate closure of the abdominal wall.

Three graspers are placed on the medial border of each rectus muscle, and provisional 'proof closure" can be attempted (under total muscle relaxation). If tension-free closure of the anterior rectus sheath appears doubtfull, synthetic mesh is applied in the retromuscular, prefascial space, preferably for augmentation or bridging, depending on the amount of expected tension. This is done by using a non-resorbable synthetic mesh which is fixed with PDS sutures to the posterior rectus sheath (Figure IV).

After completion of this tension-reducing technique, the abdominal wall can be closed with running looped PDS (polydioxanone-S, No 1). We strictly apply the suture length : wound length ratio of 4 : 1 and therefore at least two looped PDS sutures are needed for closure of an average laparotomy wound.[32]

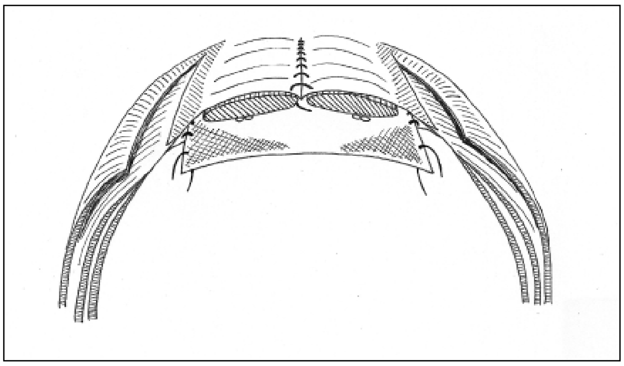

Figure IV. position of the retromuscular, prefascial mesh after performing the CSM.

The large subcutaneous and intra-muscular dissection surfaces can cause postoperative haematoma's and do have a tendency to create seroma's later on. We try to limit the risk of these wound-related complications by very strict (diathermic) dissection, meticulous sponge tamponade followed by bilateral insertion of suction drains in this plane. Subcutaneous tissue is closed using Vicryl 3.0 and the skin is closed with staples.

Postoperative rehabilitation

Patients are usually extubated at the OR and after a short recovery stay taken to the surgical ward postoperatively. In case of long lasting surgery or concomitant surgical procedures (eg. reconstruction of the gastrointestinal tract) in patients with considerable co-morbidity, intensive care unit (ICU) admission should be anticipated. Prolonged intubation and subsequent ICU stay is not routinely performed. Strict bedrest is advised for 5 days and preoperatively initiated physiotherapy is started. Drains are allowed to stay in situ until the 5th postoperative day (seroma's can develop after 3 or 4 days) although the use of drains has proven not to reduce the incidence of wound related complications.[33] Additionally, when patients are mobilised, an abdominal binder is applied to further diminish the risk for seroma formation, by continuous adaptation of the created large subcutaneous plane, not for alleged abdominal wall strength. Seroma formation can not be completely prevented by these measures but in our personal experience it has a positive influence on the number of wound related complications and the amount of seroma. Omitting a pressure dressing does not produce an increased risk for wound related complications in umbilical hernia repair in children, but patients with a large abdominal wall defect have a much heavier, floppy abdominal skin with a much larger amount of subcutaneous fat in this huge layer of dissection.[34] This consequently creates a higher risk for seroma and other wound related complications.

Summary

Closure of huge abdominal wall defects by using the CSM is a well accepted surgical technique. Due to the invasiveness of this procedure, especially in patients who had multiple previous laparotomies and are known to have serious co-morbidity, the risk for postoperative complications can not be neglected. We have summarized our experiences with this technique over the last 10 years, hoping to provide usefull recommendations which might prevent some well known complications (Table I).

As wound complications are very common after the CSM, a prospective randomised trial, investigating our postoperative suggestions, would especially be interesting because they have the most traditional, expert opinion character.

Table I. Recommendations for use of the Components Separation Method

inclusion	**pre-operative**	**technical procedure**	**post-operative**
midline defects	dietician	excision of previous mesh	subcutaneous drains for 5 days
width > 5 cm	CAT-scan	adhesiolysis	strict bedrest 5 days
surface > 50 cm2	physiotherapy	respect skin/subcutis	abdominal binder
symptomatic	eliminate contamination	spare internal oblique muscle	physiotherapy
imminent fistulation		limited tension reduction requires mesh augmentation	
		respect the “fatty triangle” for mesh placement	
		excision of “neo-linea alba”	
		SL : WL = 4 : 1	

SL : WL = suture length : wound length ratio [32]
CAT = Computerized Axial Tomography

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Chapter 3 - Anatomical considerations for surgery of the anterolateral abdominal wall

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Introduction

The most important functions of the abdominal wall are protection, compression and retaining the abdominal contents, flexion and rotation of the trunk and forced expiration.

The musculofascial components serve the first functions very adequately but herniations at the epigastric, umbilical, femoral and inguinal area as well as along the semilunar line, can occur. Apart from these predictable weak areas, incisional hernias may develop in 10% of all patients after a midline laparotomy and should be regarded as a serious clinical and disabling condition.

Closure of a large or recurrent abdominal wall defect using the Components Separation Method (CSM) is a well accepted surgical method. This tension reducing repair by means of the patient's own tissues was first described by Oscar Ramirez in 1990.[1] With this technique skin and subcutaneous tissue are mobilised bilaterally and the aponeurosis of the external oblique muscle is incised pararectally, about 1 cm lateral to the rectus muscle. The avascular plane between the external and internal oblique muscles can be separated easily by blunt dissection (Figure I & II).

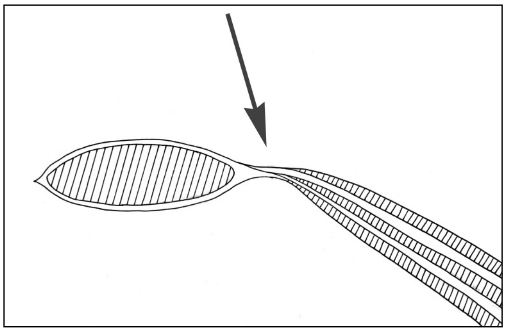

Figure I. Skin and subcutaneous tissue are mobilised and the aponeurosis of the external oblique muscle incised pararectally, about 1 cm lateral to the rectus muscle.

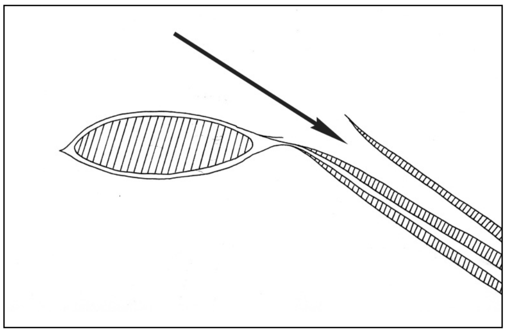

Figure II. The external and internal oblique muscles can be separated by blunt dissection.

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This mobilisation is carried out as far as the posterior axillairy line. Furthermore, the rectus muscles are separated from the posterior rectus sheath, in order to create additional translation (Figure III). Individual contribution of these dissections to the total amount of translation has never been documented but mobilisation of the posterior rectus sheath is believed to be of minor relevance.

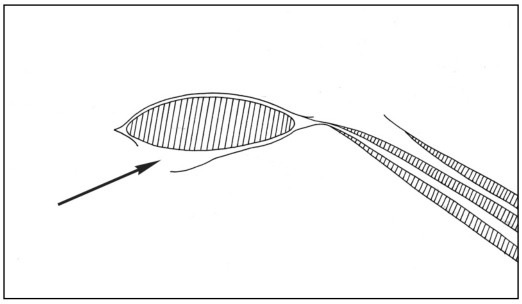

Figure III. Additionally the rectus muscle can be separated from the posterior rectus sheath.

According to Ramirez' cadaver study (n=10) a total advancement to the midline of five, ten and three cm on either side in the epigastric, umbilical and suprapubic region respectively, can be realised.
When looking at each individual direction of fibers and action, we can draw vectors of movement for all three oblique muscles (Figure IV). The external and internal oblique muscles are more or less counteracting. Taking the external oblique out of action can theoretically allow the internal and transverse oblique muscles to rotate medially around its centre of origin, thereby facilitating a more medial and caudal translation of the rectus muscle.

Material and methods

In eight adult human cadavers, six men and two women, anatomical changes due to the CSM were measured. Because it can be theorized that in 'fresh' cadavers, rigor mortis could limit the release and subsequent muscular translation significantly, we examined four 'fresh' cadavers prior to post-mortal examination and four thawn, freshly deep frozen (non-fixed) cadavers. The cadavers were prepared by excision of skin and subcutaneous tissue of the abdominal wall, from sternal to pubic bone.

In the ‘fresh’ cadavers the subcutaneous plane was prepared through a midline incision, which enabled clear vision of the abdominal wall aponeuroses.

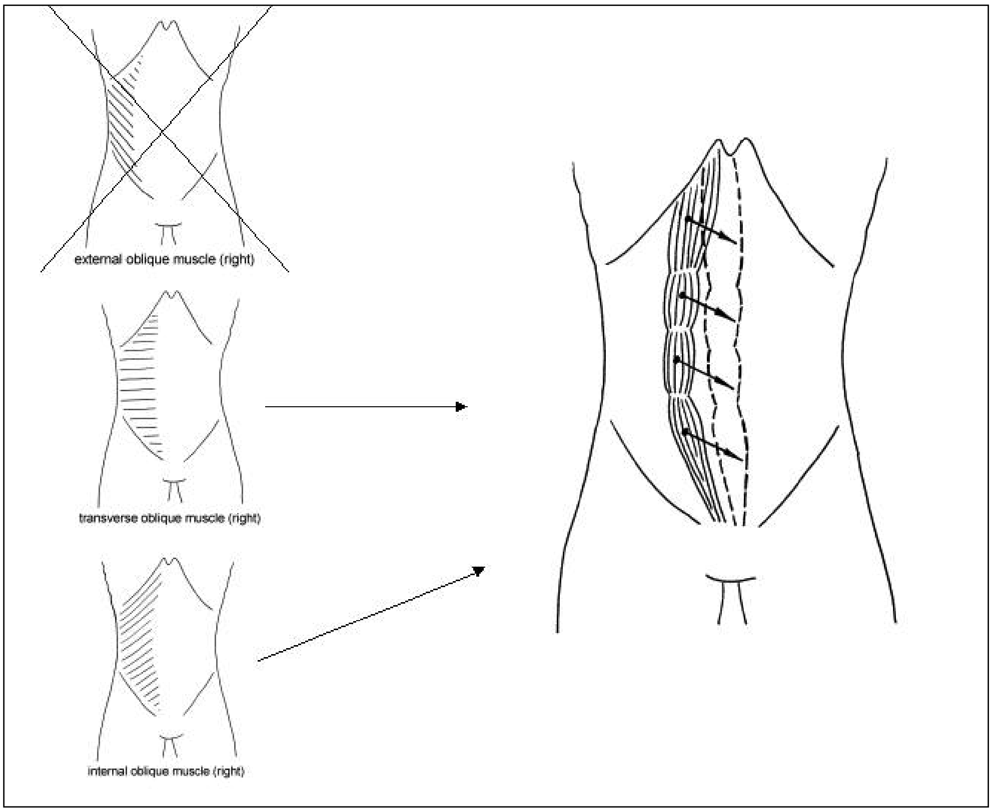

Figure IV. Taking the external oblique out of action can theoretically allow the internal and transverse oblique muscles to rotate medially around its centre of origin, thereby facilitating a more medial and caudal translation of the rectus muscle.

Only a few clinical experiences with this technique have been published and the underlying anatomical and physiological mechanisms have never been described extensively.[2-8]

In this cadaver study we examined the anatomical changes after component separation and tried to find an explanation for the impressive mobilising effect of the CSM.

Figure V. The cadavers were prepared by excision of skin and subcutaneous tissue of the abdominal wall, from sternal to pubic bone.

In the thawn cadavers, skin and subcutaneous tissue was excised (Figure V). Geometry of the cadaver was recorded before it was placed spirit level on a specially designed measuring device (Figure VI). This consisted of a heavy top with metal bars at the corners. A plastic measure-frame was slid over the bars and lowered to the individual level of the abdominal wall (Figure VII). Xiphoïd process and symphysis were placed in the midline of the frame to allow exact measurement.

Figure VI. Cadavers were placed spirit level on this specially designed measuring device.

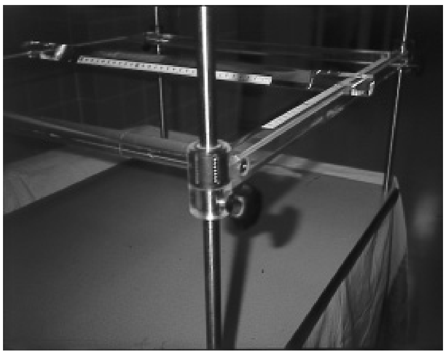

Figure VII. A plastic measure frame can be slid over the bars and lowered to the individual level of the abdominal wall.

To enable measuring at three different levels the xiphoid-pubical line (linea alba) was divided in quarters and the three borders were marked. In all cadavers a median laparotomy was performed and fixation-wires (PDS-1) were placed at the three marked sites (1 cm lateral to the linea alba). Tearing out of the fixation-wires was prevented by placing metal-rings above and under the rectus abdominis muscle (Figure VIII). Each wire was provided with a calibrated weight of 1000 mg, which hang freely over the edge of the frame. Two-dimensional coordinates were measured to obtain baseline information. After that, the CSM method was performed and coordinates were measured again. Now the direction and amount of translation of the three coordinates were determined. All cadavers were bilaterally measured independently by two observers. We did not routinely detach the rectus muscle of its attachment to the rib cage.

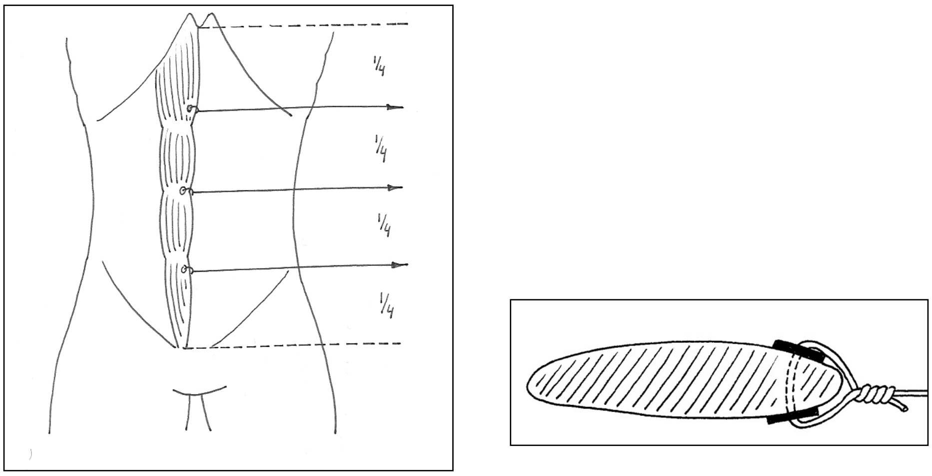

Figure VIII. The xiphoid-pubical line (linea alba) was divided in quarters and the three borders were marked. Fixation-wires (PDS-1) were placed at the three marked sites (1 cm lateral to the linea alba) and tearing out was prevented by placing metal-rings above and under the rectus abdominis muscle.

Results

The mean distance from the xiphoid process to the pubic bone was 32 cm (27 – 41) whereas the mean distance between left and right Superior Iliac Spine (SIS) was 25 cm (22 – 30). The mean abdominal circumference measured 98 (83 – 110), 93 (77

– 106) and 95 (79 – 111) cm at the level of the xiphoid process, umbilicus and SIS respectively.
The mean translation in the lateral-medial direction after release of the external oblique muscles measured 2.2 (0.7 – 4.1), 3.7 (1.0 - 5.7) and 3.5 (1.2 - 4.9) cm at each side. The mean translation in a caudal direction was 0.5 cm (0 – 1.8). Seven cadavers showed a mean translation of 1.0 cm (0.5 – 1.5 cm) of the uppermost measuring point in a cranial direction. After the additional release of the rectus muscle from it's posterior sheath, translation increased further but less than after the first procedure: a lateral-medial translation was achieved of 2.7 (0.7 – 5.2), 4.5 (0.6 – 6.9) and 4.0 (1.3 – 5.4) cm.

Discussion

Large, chronic incisional hernias are characterised by lateral retraction of the flat abdominal muscles. Sometimes the overlying skin is so thin and atrophic that erosion leads to chronic ulceration, sinus formation or enterocutaneous fistulation. Treatment of these large abdominal wall defects is complex which is reflected by a high recurrence rate up to 44% in literature.[9-12] Size, site, degree of contamination of the abdominal wall defect and the amount of viable tissue are determinants for the choice of surgical procedure. Marked loss of muscular substance requires open mesh repair (non-dynamic) or a Components Separation Technique (dynamic, non-mesh) to overcome the unacceptable high recurrence rate after open suture repair.[3,4,12-14]
The ideal method of reconstruction of large incisional hernias should regain the abdominal visceral domain, by means of a dynamic and tension free reconstruction, which is incorporated in the abdominal wall. The CSM (and its modifications) seems to fullfil these requirements and has become an accepted method for the treatment large abdominal wall defects.[3-8,13]
In this cadaver study we tried to document how much translation of the retracted abdominal wall muscles can be achieved and how this process takes place under standard conditions when using the CSM. The mean unilateral translation in medial direction was 27, 45 and 40 mm at the level of xiphoid, umbilicus and SIS respectively,

thereby allowing closure of defects measuring 5.4, 9.0 and 8.0 cm at these levels. We could not come up to the data from the original study because medial translation did not benefit from release of the posterior rectus sheath as much as we expected. Release of the external oblique muscle seems to produce more benefit to abdominal wall closure than does release of the posterior rectus sheath. Nahas[15] also found a more significant decrease in the traction index (traction force at midline / translation to midline) after release of the external oblique aponeurosis compared with the release of the posterior rectus sheath.

Mean translation in caudal direction of the coordinates at the umbilicus and SIS level were 5 and 2 mm. In contradiction to our theory the upper part of the abdominal wall moved in a cranial (instead of caudal) direction in seven of eight cadavers with a mean translation of 10 mm.

Our disappointing results of translation can not be explained by rigor mortis because Ramirez prepared his specimen under comparable conditions (fresh cadavers). Ramirez routinely detached the rectus muscle of its rib cage attachment which probably attributes to the more impressive mobilisation. We found no statistically significant difference between the mean medial translation in fresh cadavers and in fresh frozen cadavers.

Based on the results of our cadaver study the hypothesis that rotation of separate tissue layers of the abdominal wall, largely accounts for the translation effect of the CSM can be rejected. More important, the minor relevance of mobilisation of the posterior rectus sheath in Components Separation Techniques is evidently shown.

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Chapter 4 - Long term results of reconstructing large abdominal wall defects with the Components Separation Method

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Introduction

Despite better understanding of possible predisposing factors and preventional measures, 10 to 15 % of all patients, having had a midline laparotomy, still develop an abdominal wall defect (AWD). Introduction of prosthetic mesh in the repair of these defects has reduced recurrence rates during recent years but long term results of reconstruction of large abdominal wall defects remain poor with recurrence-rates still up to 44 %. Among others, incorrect application of the mesh might be an important factor for this number. Moreover, surgical repair of recurrences is demanding and stands for major surgery with considerable concomitant morbidity.
In theory, the goal of any reconstruction of an AWD should be full restoration of abdominal wall function with an intact muscular coverage, prevention of visceral eventration and adequate soft tissue conditions. Various techniques to achieve this have been advocated, but up to now there is still no “golden standard” for surgical repair of AWD’s. Important factors for the choice of technique are the size and site of the defect, availability of viable tissue and degree of contamination. One possible solution for closure of large median AWD’s is the use of local tissue after a tension relaxing procedure i.e. Components Separation Method (CSM), first described by Ramirez[1] in 1990. With this technique the abdominal midline can often be reconstructed in a one-stage procedure without the need of a musculofascial transfer (distant flaps) or the use of prosthetic material.
The purpose of this study is to evaluate our long term results of large abdominal wall reconstruction by means of the CSM with special interest to recurrences, the influence of contamination and additional use of prosthetic mesh.

Patients and method

In a six year period we treated 95 patients with large mid-line AWD’s at the University Medical Centre in Utrecht and at the Jeroen Bosch Hospital in ‘s-Hertogenbosch. Defects exceeding 5 cm in width and 50 cm^2 were considered as large. All patients had debilitating symptoms or local conditions which urged surgical intervention (e.g. an AWD with atrophic skin-coverage and subsequent imminent enterocutaneous fistulation). Population characteristics are shown in Table I. All operations were planned procedures (no emergencies) and performed by an experienced surgeon under peri-operative antibiotic prophylaxis using amoxicilline/clavulan acid 1200 mg iv. 30 minutes prior to incision (repeated after three hours if necessary). In cases of bacterial peritonitis or drained abscesses antibiotics were continued for three days. Bowel preparation was not routinely performed. Contamination was classified according to the National Research Council (NRC).[2]

Tabel I. Patient characteristics n = 95

age	52		
male / female	48 / 47		
BMI	28 (22,0 – 36,9)	5.7	SD
COPD	13		
previous laparotomies	3 (0 – 8)	2	SD
ostomy	22		
fistulation	19		
skin defect	30		
size of defect	230 (60 – 800)	177	SD

age = median age in years
COPD = Chronic Obstructive Pulmonary Disease
size of defect = mean size in cm^2
BMI = median Body Mass Index
laparotomies = mean number
SD = Standard Deviation

Previously implanted mesh was removed if possible and the Component Separation Method was performed, as illustrated in Figure I. After bilateral mobilization of skin and subcutaneous tissues, the aponeurosis of the external oblique muscle was incised pararectally, about 1 cm lateral to the rectus muscle. Then the external and internal oblique muscles were separated by blunt dissection, which is rather easy due to loose connective tissue and the avascularity in this plane (Figure II). This mobilization was carried out as far as the posterior axillary line in order to facilitate medialization of the rectus abdominus muscle to achieve tension reduced closure of the abdominal wall defect.

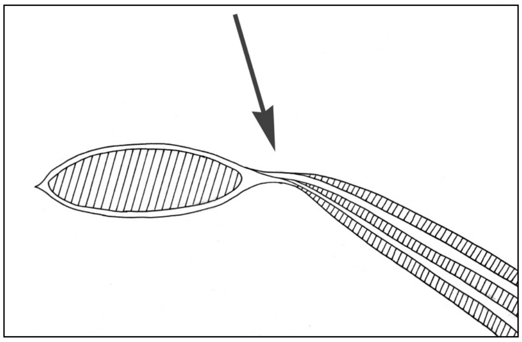

Figure I. Skin and subcutaneous tissue are mobilised and the aponeurosis of the external oblique muscle incised pararectally, about 1 cm lateral to the rectus muscle.

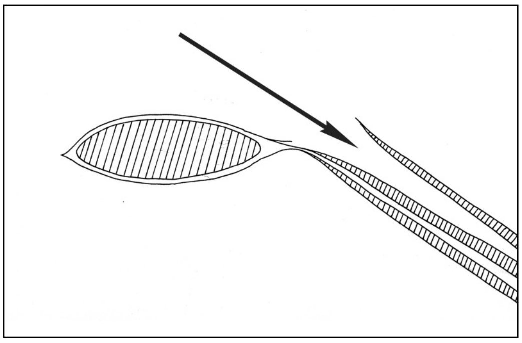

Figure II. The external and internal oblique muscles can be separated by blunt dissection.

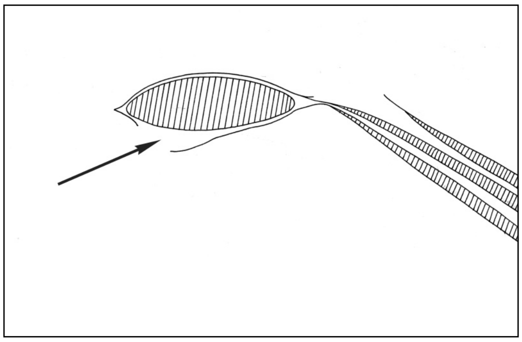

Figure III. Additionally the rectus muscle can be separated from the posterior rectus sheath.

Due to this extensive dissection large wound surfaces are created, essentially including the entire ventral abdominal wall. To diminish the risk of skin necrosis and seroma formation we used an alternative approach in three cases: instead of bilateral subcutaneous mobilisation starting at the midline, bilateral skin-incisions were made directly at the level of the rectus abdominis/external oblique-junction. The separation of the external and internal oblique muscle could then be made directly through this approach. After closure of the linea alba, the consequent lateral skin-defects were covered by split-skin grafts. This method was not routinely performed for cosmetic reasons.

In addition, the rectus muscles were separated from the posterior rectus sheath which increases its medialization (Figure III). This procedure was normally performed bilaterally, but in cases with an ostomy this was only done contralaterally in order to prevent skin necrosis around the ostomy. After excision of the fibrotic fascial edges, the midline was closed with looped PDS®(polydioxanone-S, nr.1) in one layer. In twenty-six randomly chosen defects a non resorbable prosthetic mesh (18 Mersilene®, 6 Prolene®, and 2 Marlex®) was used as augmentation, being fixed with PDS® sutures in the retromuscular space between the rectus muscle and the posterior rectus sheath, with at least 5 cm overlap at all sides (Figure IV). The decision as to whether mesh augmentation was used was strictly at random because these patients participated in different randomized trials. Bilateral suction drainage was used in the subcutaneous space.

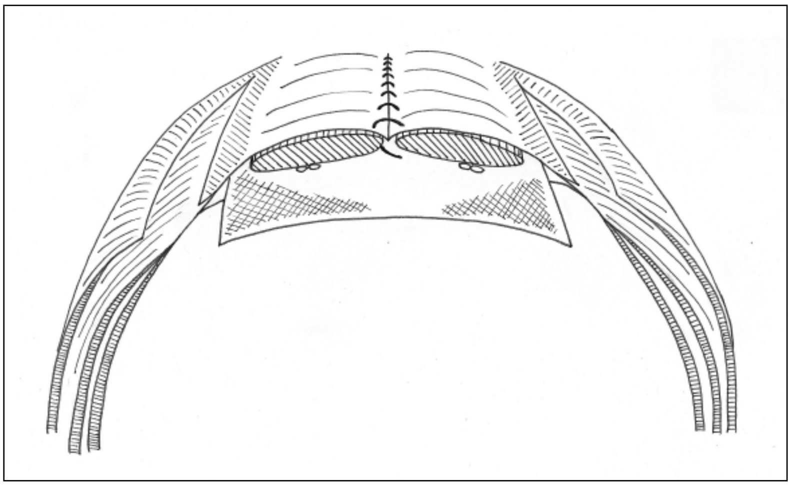

Figure IV

The skin was closed with staples in cases with NRC-III contamination. When NRC-IV was encountered the skin was just covered with a dressing. An abdominal binder was used for seven days, in order to limit seroma and haematoma formation. We defined postoperative wound infections according to the criteria for surgical site infections of the U.S. Centers for Disease Control.[3]

Information was obtained from the patient's general practitioner whether he or she was still alive and had not moved. All patients were invited to visit the outpatient clinic for an interview and physical examination with special attention for recurrences. Patients who were unable or unwilling to travel were visited at their private address by the authors, hereby accomplishing 100 % follow-up. Every patient was asked to complete a questionnaire concerning daily life activities (ADL). This questionnaire has been applied in the past as being part of a National Health Survey in the Dutch population by the Central Bureau of Statistics and has been used for physical performance assessment after inguinal hernia treatment.[4,5]

Short term results

Patients were operated in a median operating time of 120 minutes (30 – 240) and with a median blood loss of 500 ml (100 – 2500 ml). In 88 % of the operations a bilateral procedure was performed (n = 84) of which more than half without mobilization of the posterior rectus sheath (n = 46). We encountered contamination in 34 operations (36%) of which 4 were NRC-IV contaminated. Patients were hospitalized for a median stay of 11 days (3 – 201) during which 58 % developed one or more complications. Most complications were grade I and required no intervention. Seven patients (7%) needed a re-operation during hospitalization. In 4 cases because of progressive seroma formation, in two patients due to postoperative hemorrhage. One patient suffered an anastomotic disruption and died after 60 days due to severe peritonitis and multiple organ failure. Another patient died after 4 days due to massive pulmonary embolism.

The most frequent complications are listed in Table II. All wound infections were superficial and could be treated by local drainage and secondary healing of the wound. Most seroma's could be aspirated at the surgical ward or in the office.

Table II. Complications of CSM

Minor complications	
superficial wound infection	24
seroma/haematoma	23
pneumonia	13
enterocutaneous fistulation	6
Major complication	
death	2

Long term results

Five patients had deceased during the follow-up period, all by unrelated causes (malignancies 4 of 5). These patients were not excluded from follow-up but we decided to use their last visit as date of follow-up which ranged from 2 to 5 years. After a median follow-up period of 48 months (1 – 95) we found 15 patients with a recurrence (15.7 %). Mean follow-up period was 49 months. Thirteen of these patients were asymptomatic and fully satisfied with their situation. Two patients with a recurrence needed a re-operation during which the CSM was performed on the contra-lateral side (they had a unilateral CSM initially) in combination with a retrofascial, preperitoneal non absorbable mesh. We found only 1 small asymptomatic recurrence (3.8%) in the group with initial mesh augmentation versus 14 (20%) in patients without augmentation (Table III). The only recurrence found in the mesh group, concerned a 60 year old male (BMI = 30) who had a recurrent fascial defect measuring 400 cm^2 which was treated with the CSM, augmented by Mersilene® mesh. In his postoperative period he developed a wound infection and had prolonged seroma formation. After 40 months we discovered an asymptomatic recurrence of 3 cm in diameter in the most cranial part of the scar, about 2 cm below the xiphoid, possibly due to a technical error.

Table III. Patient characteristics (mesh vs non-mesh)

n=95	n	m / f	age	BMI	size	time	TBL	contam.	WI	seroma	recurr.
CSM + augm.	26	13/13	58	28,8	225,0 (SD 126,9)	115 (SD 29)	500 (SD 223)	5 (19%)	7	4	1 (4%)
CSM	69	36/33	52	26,8	251,3 (SD 209,1)	120 (SD 43)	650 (SD 608)	29 (42%)	17	19	14 (20%)

CSM Components Separation Method
age mean age (years)
size mean defect size in cm^2
TBL median total blood loss (ml)
WI number of woundinfections
SD Standard Deviation
m / f male / female
BMI median Body Mass Index
time median operation time (minutes)
contam. number of contaminated procedures
recurr. number of recurrences
augm. augmentation with mesh.

In six patients we found postoperative enterocutaneous fistulation. Three of those patients had fistulation pre-operatively and in all three, previously implanted Marlex® mesh could initially only be partially removed and all three required reoperation. Three other patients had low volume fistulas which healed spontaneously, so eventually all patients recovered from fistulation. In seven patients a non-infected skin defect was present but no signs of enterocutaneous fistulation were observed. Thirteen patients had complaints about the cosmetic result of the operation and 12 patients had used psychological counselling for more than 6 months in the postoperative period.
All patients had completed the questionnaire concerning daily life activities (ADL). Twenty-nine patients (30 %) reported to have one or more serious restriction in daily life activities. In most cases this concerned restrictions in heavy weight bearing (n=22) and/or tying their shoe-laces (n=12).

Discussion

Long term results of patients treated for massive and often recurrent abdominal wall defects in large series are lacking in literature. Due to the great variations in aetiology, abdominal wall history and present pathology, treatment has to be tailored individually and often customized in detail, as we stated before.[6] Different treatment strategies for these patients are therefore difficult to investigate in randomized controlled trials and the optimal treatment for an individual patient can not be derived from an algorithm.

Although minimal invasive approaches are being used more often for incisional hernia repair in general, most patients with massive and multiple recurrent ventral hernias will need an open reconstruction. Laparoscopic series report recurrence rates up to 17 %. Recently Perrone et al.[7] published his short results of laparoscopic incisional hernia repair in 116 patients. Only 21 % of his patients were operated for a recurrent hernia and the mean fascial defect measured 115 cm^2. These patients were operated in 157 minutes, with a conversion rate of 17 % and a recurrence rate after 22 months of 9.3 %. One of the specific risks of laparoscopic repair is accidental enterotomy which may remain undetected during surgery. In this study 11.4 % of patients with recurrent ventral hernia suffered from this hazardous complication. All were treated by laparotomy, bowel-resection and primary closure of the fascial defect because contamination apparantly ruled out an additional procedure. One patient developed multiple organ failure and died.

Because of the alleged high risk for infection in case of encountered contamination, traditionally one-stage reconstruction, with or without mesh, is abandoned and a multistage procedure is chosen.[8,9] The latter procedure is time consuming, often not finalized and accompanied by considerable morbidity. However, recent reports suggest that definitive closure despite contamination is successful and does not necessarily exclude the use of synthetic mesh.[10,11,12]

For open reconstruction, abdominal wall defects can either be treated by bridging (with synthetic material or the patients' own tissue) or closure of the abdominal wall after tissue expansion or relaxing incisions.[6] The latter will restore circumferential functional muscular support and (by avoiding the use of mesh) prevents complications of direct contact between non resorbable mesh and the bowel. The ultimate goal of reconstruction of the abdominal wall is preventing visceral eventration by dynamic, muscular support and adequate soft tissue coverage. We therefore prefer closure of large, recurrent abdominal wall defects in a one-stage manner by using the Components Separation Method.

Oscar Ramirez[1] first described the possible medial mobilization of the rectus muscle by using his tension-reducing technique. Nahas[13] documented that these relaxing incisions and undermining of the external oblique muscles, resulted in a reduction of the necessary force for medial mobilization. In a cadaver study we additionally found that release of the external oblique muscle produces more benefit to abdominal wall closure than release of the posterior rectus sheath.[14]

Few reports have been published about the results of the CSM during the last decade with recurrence rate varying from 5 to 32 %.[1,15-20] Most studies are hampered by either study size or time of follow-up (Table IV).

These results are in accordance with a recent population based study of more than 10.000 patients. Flum[21] reported a 12.3 % reoperation rate within the first 5 years after initial incisional hernia repair (irrespective of the technique). He also found a 5-year reoperative rate of 23.8 % after the first and 35.3 % after the second incisional hernia repair.

4

Table IV. Publications on the results of the CSM

author	year	study size	contamination	recurrence %	follow-up
Ramirez[1]	1989	11	3	0	?
DiBello[16]	1996	35	15	8.6	22
Girotto[17]	1999	33	3	6.1	21
Shestak[18]	2000	22	?	5	52
Lowe[19]	2000	30	?	10	12
De Vries R [20]	2003	43	15	32	16
Van Geffen	2006	95	34	15.7	49

study size = number of patients
contamination = number of contaminated procedures
follow-up = **mean** follow-up in months
CSM = Components Separation Method

In this study we analyzed a large series of patients with massive abdominal wall defects treated with the CSM, during a follow-up period of 4 years. At this long term follow-up we found 15, mostly asymptomatic, patients with a recurrence (15.7 %). Most patients could perform daily life activities without limitations, with the exception of heavy weight bearing in 22 patients and tying shoe-laces in 12 patients (Table V). Theoretically, the abdominal wall can become less flexible after synthetic mesh augmentation and can therefore cause more restrictions in daily life, as opposed to non-mesh repair. But it was striking to see that patients with postoperative limitations in heavy weight bearing or tying shoe-laces, were equally divided between treatment with and without mesh augmentation. In this series, the application of synthetic mesh for augmentation of abdominal wall reconstruction by means of the CSM, did not create more limitations in daily life activities.

Table V. Limitations in daily life activities

patients	n	tying shoe-laces	heavy weight bearing	total number
CSM + augm.	26	3	6	8
CSM	69	9	16	21
total	95	12	22	29

total number = total number of patients with one **or more** serious limitations
augm. = augmentation with mesh
n = number of patients
CSM = Components Separation Method

A large amount of patients admitted to have had psychological problems during hospitalization and 12 patients needed psychological counselling for more than 6 months after discharge. All 12 patients held the longevity of their illness, characterized by multiple operations and intensive care admissions, accountable for this.

At present time there are no reports on the additional benefit of mesh augmentation during the CSM regarding recurrence. Dibello[16] could not achieve a tensionless repair with the CSM in 15 of his 35 patients. In these cases reconstruction was augmented by using a resorbable mesh (Vicryl®) as an overlay and anchored beyond the semilunar line, but the specific result of these augmented repairs are unknown. Lowe[19] reported the additional use of mesh in 10 of the 30 patients who underwent an open CSM but the indication-, position- and type of synthetic mesh is unclear as well as the follow-up of this group of patients.

The coïncidental (random) use of non absorbable mesh in a preperitoneal position in our study, for augmentation of the CSM, provided remarkable results. Both groups of patients (with and without mesh augmentation) are comparable, as shown in Table III, with the exception of the amount of contaminated procedures. We found only 1 small asymptomatic recurrence in the group with initial mesh augmentation (3.8%), versus 14 in patients without augmentation (20%). Analysis with a Fisher's exact test, proved this difference to be statistically significant ($p = 0.036$). The latter 14 patients were equally divided between contaminated and non-contaminated procedures. The higher recurrence rate in patients without mesh augmentation, therefore does not seem to be correlated to the presence of contamination. Although we could not derive it from the operative report, we suspect technical failure to account for the single recurrence in the mesh augmented group. Careful dissection of the "fatty triangle" and sufficient mesh overlap are essential in this area to prevent a subxiphoidal recurrence, as Conze[22,23] reported recently.

We conclude that massive and recurrent abdominal wall defects can be safely treated by using the Components Separation Method, given the grotesque pathology. This, despite the amount of superficial wound infections in about 25% of all cases. Mortality was unrelated to the surgical technique. The combination of the CSM with non-absorbable mesh augmentation in the pre-fascial retromuscular space, clearly shows favourable results over mesh-less reconstruction with the CSM. Future investigation in a large prospective randomized trial is needed to validate this finding.

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Chapter 5 - Surgical treatment of large contaminated abdominal wall defects

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Introduction

Up to now there is no "gold standard" for the surgical treatment of large abdominal wall defects. Size, site, relative or absolute lack of viable tissue and degree of contamination are determinants for the choice of surgical procedure. Small defects up to 5 cm in width are generally closed primarily.[1] For larger defects there are several options: primary closure under tension with or without augmentation by insertion of synthetic material, closure after performing relaxing incisions, sometimes including separation of the lateral abdominal muscles, again with or without a supporting mesh and finally bridging the defect (laparoscopically) with synthetic material or by transposition of (remote) musculo-fascial flaps.[2-26]

Repair of a large and severely contaminated abdominal wall defect is an even greater problem, in which the use of non-absorbable mesh also has been ill-advised Due to an alleged high infection risk and subsequent morbidity, most patients are currently treated with a multi staged procedure.[27] Because of the extended time of disabling morbidity during the different stages of the procedure and its high complication rate, an alternative for this multi staged procedure is needed.

In our department, large abdominal wall defects are routinely closed in a one stage manner by using the Components Separation Method (CSM) as described by Ramirez et al[8], with or without synthetic mesh augmentation. In order to evaluate our experiences with one stage contaminated abdominal wall repair, we performed this retrospective analysis.

Patients and methods

In the years 1996 through 2000, twenty-six patients with large contaminated abdominal wall defects were treated. Contamination was classified according to the National Research Council [28] (Table I and III).

Table I. Grading of contamination

grading*	contamination	example	infection-rate**
I	clean	thyroid surgery	1-2 %
II	clean contaminated	small bowel resection	10-20 %
III	contaminated	colonic surgery	20-35 %
IV	dirty	abces	20-50 %

* = according to the National Research Council [28]
** = without antibiotics

All operations were performed electively by an experienced surgeon and under peri-operative antibiotic prophylaxis using amoxicilline/clavulan acid 1200 mg iv., 30 minutes prior to incision (repeated after three hours if necessary). In case of bacterial peritonitis or opened abcesses with major contamination, antibiotics were continued for three days. Bowel preparation was not routinely performed.

Previously implanted mesh was removed and the Component Separation Method was performed, as illustrated in Figure I. After bilateral mobilisation of skin and subcutaneous tissues the aponeurosis of the external oblique muscle was incised pararectally, about 1 cm lateral to the rectus muscle. Then the external and internal oblique muscles were separated by blunt dissection. This manoeuvre is rather easy due to loose connective tissue and the avascularity in this plane (Figure II). This mobilisation was carried out as far as to the posterior axillary line in order to facilitate medialisation of the rectus abdominus muscle and tension free closure of the abdominal wall defect.

This procedure creates large wound surfaces covering the entire ventral abdominal wall. To overcome this problem we used another approach in three cases: instead of bilateral subcutaneous mobilisation, bilateral skin-incisions were made directly at the level of the rectus abdominis/external oblique-junction. After closure of the linea alba, the remaining lateral skin-defects were covered by split-skin grafts. This method was not routinely performed for cosmetic reasons.

Additionally, the rectus muscles were separated from the posterior rectus sheath (Figure III). This procedure was routinely performed bilaterally, but in case of an ostomy this was only done contralaterally due to fibrosis limiting the dissection. After excision of the fibrotic fascial edges, the defect was closed with looped PDS® (polydioxanone-S, nr.1) in one layer. Four defects (all in patients with NRC-III contamination) could not be closed without unacceptable tension, so the remaining defect was bridged with a polyester mesh, which was fixed with a running PDS® suture in the prefascial retromuscular space, with sufficient overlap of the edges. Bilateral suctiondrainage was used in the subcutaneous space. Skin was closed with staples in case of NRC-III contamination. When NRC-IV was encountered the skin wound was just covered with sterile dressing. An abdominal binder was used for seven days to limit seroma and haematoma formation. We defined postoperative wound infections according to the criteria for surgical site infections of the U.S. Centers for Disease Control.[29]

For follow-up all patients were invited to visit the outpatient clinic where the patients were interviewed and a physical examination was performed with special attention for recurrence.

Table II. Patient history

age	M/F	disease/condition	initial treatment	complication/clinical course	result
51	m	coloncancer	low anterior resection	anastomotic disruption	IAS, laparostomy
49	m	leucaemia	splenectomy	postoperative bleeding	IAS, laparostomy
47	v	M. Crohn	hemicolectomy	anastomotic disruption	IAS, laparostomy
69	v	diverticulitis	Hartmann procedure	necrosis colostomy	IAS, laparostomy
72	v	coloncancer	sigmoid resection	anastomotic disruption	IAS, laparostomy
56	m	pancreatic cancer	Whipple procedure	anastomotic disruption	IAS, laparostomy
42	m	Non Hodgkin Lymfoma	hemicolectomy	wound infection	incisional hernia
50	m	M. Crohn (perf. toxic colon)	total colectomy	intra-operative contamination	IAS, laparostomy
46	m	AAAA (ischaemic sigmoid)	sigmoid resection	anastomotic disruption	IAS, laparostomy
47	v	colonic polyps	coloscopic polypectomy	bowelperforation	necrotizing fasciitis
43	m	perforated diverticulitis	Hartmann procedure	intra-operative contamination	IAS, laparostomy
66	v	M. Crohn	ileocecal resection	anastomotic disruption	IAS, laparostomy
56	m	perforated diverticulitis	Hartmann procedure	intra-operative contamination	IAS, laparostomy
58	m	huge rec. umbilical hernia	open mesh repair	5th recurrence	rec. incisional hernia
31	m	small bowel obstruction	ileocecal resection	anastomotic disruption	IAS, laparostomy
30	v	CBD stone	ERCP	bowelperforation	IAS, laparostomy
33	m	polytrauma	emergency small bowel resection	pancreatitis	laparostomy
52	v	AAAA	bifurcation prosthesis	burst abdomen	laparostomy
54	m	coloncancer	transverse colon resection	anastomotic disruption	IAS, laparostomy
61	m	coloncancer	low anterior resection	anastomotic disruption	IAS, laparostomy
74	v	diverticulitis	low anterior resection	anastomotic disruption	IAS, laparostomy
38	v	pancreatitis	conservative treatment	clinical deterioration	laparostomy
46	m	colonperforation (stabwound)	colonic wedge resection	intra-operative contamination	IAS, laparostomy
69	m	AAAA	bifurcation prosthesis	burst abdomen	laparostomy
41	v	cervical cancer	Wertheim-Meigs	wound infection	incisional hernia
46	v	perforated mesenteric ischemia	small bowel resection	intra-operative contamination	IAS, laparostomy

AAAA = Acute Aneurysm Abdominal Aorta
CBD = Common Bile Duct
IAS = Intra Abdominal Sepsis
ERCP = Endoscopic Retrograde Cholangio Pancreaticography

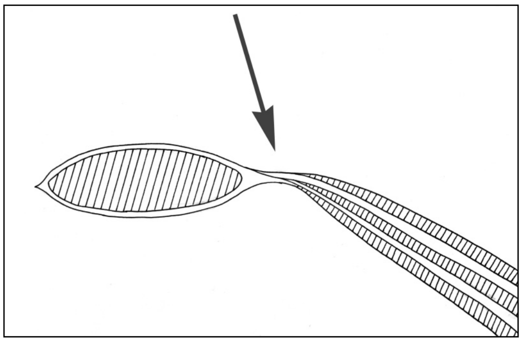

Figure I. Skin and subcutaneous tissue are mobilised and the aponeurosis of the external oblique muscle incised para-rectally, about 1 cm lateral to the rectus muscle.

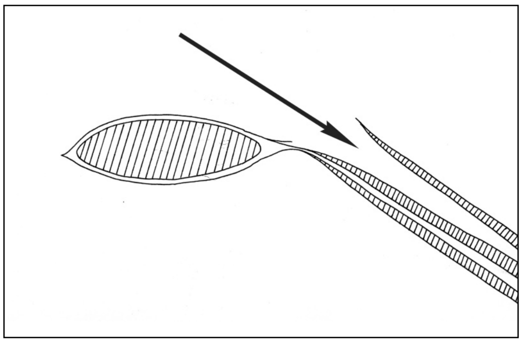

Figure II. The external and internal oblique muscles can be separated by blunt dissection.

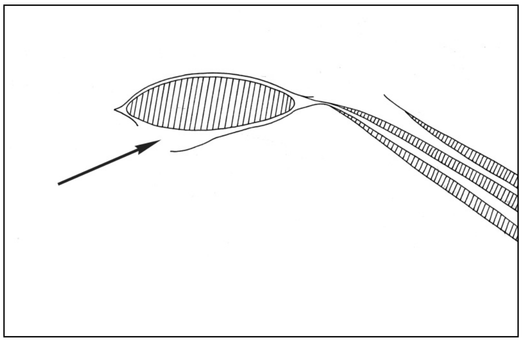

Figure III. Additionally the rectus muscle can be separated from the posterior rectus sheath.

5

Short term results

Fifteen men and 11 women with a median age of 49 (30 - 74) years had a mean defect of 267 cm^2 (60 - 800), all after midline incisions. Median operating time was 125 minutes (60 - 200). Postoperative morbidity was encountered in 17 patients leading to re-operations in two (Table III). Clinical significant seroma formation was seen in 3 patients, all treated by needle-aspiration. Five superficial wound infections were seen and treated by surgical drainage under local anaesthesia and secondary healing of the wound. In four of these five patients previous applied synthetic material had been removed during the initial procedure. Respiratory insufficiency, with pneumonia (n=3) and sepsis (n=2), were also encountered. None of the four patients with mesh-augmentation developed a wound-infection, seroma or haematoma. Three patients had recurrent enterocutaneous fistulation which all healed. Two healed spontaneously (low volume fistulas), the other after reoperation. One patient suffered an anastomotic disruption and died after 60 days due to severe peritonitis and multiple organ failure. The median hospital stay was 15 days (4 - 201).

Long term results

Three patients were lost for long term follow-up. No recurrence was found during their median follow-up of 7.5 months. Of the remaining 23 patients, four had deceased (at a median follow up of 24 months) due to unrelated causes with no recurrence at their last visit. The median follow-up period was 27 (13 – 78) months. None of the patients had been aware but physical examination revealed two small asymptomatic recurrences (8%). No signs of skin ulceration or persistent fistulation were seen. Five patients experienced one or more serious limitations in daily activities: restriction in heavy weight bearing was most frequently mentioned.

Eight of 19 patients had psychological counselling during the last months. All patients related this to the longevity of their illness, characterised by multiple operations and intensive care admissions.

Table III. per- and postoperative findings

		cause of peroperative contamination					postoperative complications				
patient	defect (cm2)	GI reconstr.	fistulation	perforation	abcess	NRC	woundinf.	seroma	fistulation	resp. insuff.	other
1	500	+	+	+		III	+				
2	380	+			+	IV					
3	210		+			III					
4	260	+	+			III			+	+	anastomotic disruption (reoperation)
5	200	+		+		III					
6	220			+		III					
7	240		+			III					
8	150	+		+		III		+			
9	800		+			III					
10	60	+				III	+		+	+	
11	180			+		III					
12	300		+			III					
13	450	+		+		III		+			
14	400			+		III					
15	160	+		+		III	+				
16	300	+				III	+			+	Douglasabcess (transrectal drainage)
17	60	+	+	+	+	IV	+		+		
18	100			+		III		+			
19	240	+			+	IV					
20	250	+				III				+	intra-abdominal bleeding (relaparotomy)
21	300	+		+		III					
22	180				+	IV					
23	500			+		III				+	
24	200		+	+		III					
25	128			+		III					
26	180		+			III				+	

defect = size of abdominal wall defect in square centimeters • NRC = National Research Council[28] • GI reconstr. = gastrointestinal reconstruction • woundinf. = woundinfection • resp. insuff. = respiratory insufficiency

Discussion

This study shows that large contaminated abdominal wall hernias can be closed succesfully in a one-stage procedure with a low recurrence rate by using the Components Separation Method.

For the surgical treatment of large contaminated abdominal wall defects, a choice has to be made between one-stage or multi-stage repair. A multi-stage procedure consist of temporary covering the defect with prosthetic material, followed by split skin grafting and finally mesh excision and definitive closure.[27] The rationale for this sequence is the fear for infectious complications in a one-stage procedure using non-absorbable mesh. This strategy is time-consuming and accompanied by significant morbidity.[30-37] Therefore immediate definitive repair seems not only a reasonable alternative. Although the CSM has good results in clean abdominal wall defects, reports in literature on reconstruction of contaminated abdominal wall defects using the CSM are scarce.[13] Dibello and Moore[10] published a retrospective analysis of 15 patients.[10] They found an overall incidence of wound-related problems of no less than 86% with 6% wound infections and 8.5% recurrences after a mean follow up period of 22 months.

Jernigan[38] and co-workers recently reported their experiences with staged management of large abdominal wall defects with the Components Separation Method. All defects resulted from the management of hemorrhagic and septic shock with the open abdomen technique. After temporary closure with absorbable mesh, mesh was removed and the defect closed by split skin grafting. Final reconstruction was achieved with a modification of the CSM and mesh augmentation in 10% of cases. After a mean follow-up period of 24 months 4 recurrences (5%) and 14 fistulations (8%) were seen. The number of contaminated procedures, wound related problems (seroma, hematoma and infection) and other morbidity is not stated. In an earlier report this group already reported that non absorbable mesh excision is time consuming and accompanied with a high morbidity.[27] This explains their switch to woven absorbable mesh which should be excised within 3 weeks to prevent mesh erosion in the bowel and subsequent fistulation. Excision of the split skin graft is another potentially hazardous step in this prolonged management which will take 6 to 12 months to final reconstruction.

In our study we treated 26 patients with large, severely contaminated abdominal wall defects by using the CSM. Two thirds of our patients suffered one or more postoperative complications, with wound infection as the most frequent. These results are comparable with those of other studies.[2,3,12,13]

Although used in only a small number we surprisingly could not establish an adverse relationship between the use of a non-absorbable mesh in the presence of contamination and wound infections, as none of the four patients with mesh-augmentation showed wound related problems. At long term follow-up only two of our patients had an asymptomatic recurrence (8%). Both patients did not have a mesh augmentation and one of them had a wound infection during the postoperative period.

Remarkable was the fact that 8 of 19 examined patients sought psychological counselling. As most of these patients attributed this to the longevity of their illness, a time consuming multi stage treatment seems less appropriate. Although some patients reported occasional abdominal pain, 14 of 19 patients could perform all daily activities without serious limitations.

Supported by the fact that contamination apparently does not exclude the use of non absorbable mesh, we conclude that large, severely contaminated abdominal wall defects can be closed in a one-stage procedure with the components separation method and the use of a supporting non-absorbable mesh in the sublay-position might be considered. This strategy seems a safe and more rapid alternative to repeated hazardous exposures during multi stage treatment, however clinical trials are necessary to put the role of mesh into a clear position.

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Chapter 6 - Prospective evaluation of lung and muscle function after Ramirez abdominoplasty in patients with abdominal wall defects.

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Submitted

Introduction

After median laparotomy approximately 10 to 20 percent of patients will develop an incisional hernia.[1-5] Primary closure of these hernias is associated with a high recurrence rate of 40 % and respiratory impairment.[4,8,9,16,17] Clinical symptoms of incisional hernias range from virtually none to serious limitations due to hampering of the digestive tract or endangered skin. Sudden incarceration of the hernia content has been described less frequently but might be life threatening. Additionally, this may cause a marked lifestyle impairment. Most complaints concern abdominal pain and back pain. Both can be explained by the disruption of the ventral muscular wall, resulting in a more ventral position of the patients' centre of gravity, which has to be compensated by an increased lumbar lordosis, often associated with de-novo or increased back pain.[6,7] In addition, disruption of the ventral abdominal musculature may also have an impact on respiratory function, due to a diminished counteract to the diaphragm by the unsupportive abdominal wall. Rives et al.[8] described the inseparable link between the chest and the abdomen and introduced the concept of "paradoxical abdominal respiration and abdominal volet". There is a clear negative correlation during surgical repair of large incisional hernias when increasing the intra-abdominal content by reduction of the hernia, with equal or even decreased containment capacity of the abdomen and hereby involuntary moving the diaphragm upwards and subsequent decreasing pulmonary compliance.[9]

Current operative techniques include primary closure, bridging of the defect by a synthetic mesh or transposition of a musculofascial flap or closure of the linea alba after rearrangement of the muscular layers, such as the Components Separation Method with or without mesh augmentation.[10,11] Generally, primary closure of large abdominal wall defects is not advised as it will result in an elevated intra abdominal pressure (IAP), due to an increased intra-abdominal content within a decreased containment capacity. This is possibly associated with respiratory impairment and unfavourable high tension at the already scarred fascial margins, with a high recurrence rate as a consequence. The basic idea in the application of the Component Separation Method (CSM), as described by Ramirez et al., for the repair of large abdominal wall defects, is an alleged tension reduced closure of the fascial defect (despite an increase of the abdominal content) achieved by the separation of

the external and internal oblique abdominal muscles, allowing the internal oblique and transversus abdominal muscle to be translated medially. Furthermore, closure of a large ventral hernia using the CSM theoretically might result in a functional restoration of the abdominal wall, recreating the possibility of “abdominal respiration” with an improved physical performance on the long term.
So far in literature no studies dealing with these two issues, in the repair of abdominal wall defects, can be found. Therefore we initiated this pilot-study in order to get any preliminary information on these issues.

Patients and methods

Eligible for this study were patients with a minimum age of 18 years with a midline incisional hernia measuring during least 50 cm^2 and a minimal width of 5 cm. The dimensions of the hernia were measured during physical examination as well as on a preoperative CT scan. Patients with serious obstructive lung disease defined as GOLD stadium II b or III (Global initiative for Obstructive Lung Disease) or patients needing emergency surgery were excluded as well as patients with concomitant restoration of the gastrointestinal tract or enterocutaneous fistula.[12,13] The latter because of an alleged influence of these features on the quality of life score. As physical performance (eg. rectus muscle) was investigated, patients with a history or presence of a colostomy were excluded.
The study was approved by our institutional review board and patients had to sign an informed consent after clinical assessment for eligibility. Preoperatively, lung and muscle function tests were carried out and the patient completed a quality-of-life-form and a questionnaire concerning daily life activities (ADL). Besides routine preoperative work-up, a CT-scan was performed for exact measurement of the fascial defect and possible additional defects. All physical performance tests and questionnaires were repeated six months after surgery.
Muscle function was tested using two tests: sit-ups and straight leg raises as described earlier by Liem et al.[14] The sit-ups required lifting the shoulders from the ground and curving of the spine, while the examiner holds the feet. The leg raises were performed with the hands placed in the neck while lifting the stretched legs. In a

single series the number of complete successful attempts was counted and compared to the preoperative series. Any increase in the number of successful attempts was defined as an improvement. Lung function tests consisted of measurement of the vital capacity (VC) and the forced expiratory volume per second (FEV_1). Improvement in lung function was defined when both, VC and FEV_1 increased with at least ten percent. Quality of life was examined using the Dutch version of the Short-form 36 health survey (Medical Outcomes Trust, Boston, MA, USA).

In all patients, the ventral hernia was closed using the CSM. In short, during this procedure which is carried out under perioperative antibiotic prophylaxis, skin and subcutaneous tissues are mobilised bilaterally and the aponeurosis of the external oblique muscle is incised pararectally, about 1 cm lateral to the rectus muscle. External and internal oblique muscles are separated by blunt dissection, as far as to the posterior axillary line in a relatively avascular plane. If necessary, the rectus muscle is bluntly separated from the posterior rectus sheath via an additional incision in the median part of the rectus sheath. The rectus muscle then can be advanced medially together with the internal oblique and transversus muscle. According to Ramirez, this renders a unilateral advancement of 5 cm in epigastrio, 10 cm at the waistline and 3 cm in the suprapubic region. Depending on the preoperative volume of the abdominal cavity, a significant increase might be achieved. In cases with diminished rectus muscle quality, a non resorbable prosthetic mesh was used as sublay augmentation, in the retromuscular space between the rectus muscle and the posterior rectus sheath. Bilateral suction drainage in the subcutaneous space and an abdominal binder were used during a week to reduce seroma and haematoma formation. In a one-year period six patients eligible for this study could be included and were followed for at least six months. The group consisted of three men and three women, aged 52 years (range 43-64 yrs), all having midline incisional hernias, located in the middle 1/3 of the xiphoid-pubic distance with a mean size of 281 cm^2 (range 96-600 cm^2). Hernia characteristics are shown in Table I.

Contamination was classified according to the National Research Council.[15] In one patient we found NRC grade 2 contamination. This was caused by iatrogenic small bowel perforation, for which resection was necessary. If prosthetic material was present, this was removed and complete adhesiolysis was performed. Four patients had a “classic” CSM; in two patients a non-absorbable sublay mesh (polypropylene/ ePTFE) was applied for augmentation.

Table I . Characteristics

patient	BMI	initial diagnosis	previous laparotomies	type of incisional hernia	size of defect (L x W in cm)	duration of herniation (months)
1	41	umbilical hernia	1	primary	15 x 20	52
2	27	hysterectomy	2	recurrence	15 x 15	18
3	26	pancreatitis	3	recurrence	20 x 12	26
4	24	colectomy	1	primary	12 x 8	16
5	19	sigmoid resection	4	recurrence	20 x 30	50
6	32	hysterectomy	3	recurrence	15 x 15	12

BMI = Body Mass Index
L & W = Length and Width of the defect

Results

During six months follow up there were no recurrences or surgery related deaths. One patient had to be re-operated upon because of skin necrosis and in another a contaminated mesh was removed. Three other patients exhibited minor wound healing disturbances, consisting of superficial wound infection in two and seroma in one. Furthermore, one patient suffered from a urinary tract infection. All patients recovered completely from these complications.
Muscle function tests showed that four patients could perform remarkably more sit-ups and leg raises compared to their preoperative situation. In one patient the number of sit-ups and leg raises remained unchanged and another could perform more sit-ups, but less leg raises. (Table II)
One patient suffered from direct postoperative respiratory insufficiency due to an intra-operative circulatory collapse, which led to exaggerated fluid substitution, resulting in pulmonary edema necessitating mechanical ventilation. As shown in Table III, both VC and FEV_1 improved in two patients. In one patient only the FEV_1 improved by more than ten percent, with minor VC improvement. In three patients lung function remained unchanged.

Table II. Outcome of muscle function tests

	Preop		6 months	
Patient	**Sit ups**	**Leg raises**	**Sit ups**	**Leg Raises**
1	0	5	10	12
2	5	8	18	24
3	10	10	15	36
4	15	15	20	10
5	15	10	15	11
6	0	6	10	15
mean	7,4	10,0	13,0	16,9

Numbers represent the performed repetitions until fatigue and/or discomfort occured

Table III. Outcome of lung function tests

	VC in (%)			FEV_1 (%)		
Patient	**Preop**	**6 months**	**change**	**Preop**	**6 months**	**change**
1	121,5	127,0	5,5	117,3	129,6	12,3
2	109,4	111,8	2,4	111,7	104,5	-7,2
3	100,3	107,5	7,2	105,4	104,8	-0,6
4	105,9	100,8	-5,1	108,7	106,7	-2,0
5	96,3	113,9	17,6	69,6	79,9	10,3
6	119,0	131,0	12,0	67,3	78,1	10,8

VC = Vital Capacity
FEV_1 = Forced Expiratory Volume (first second of forcefull exhalation)
All parameters are expressed in % of the mean predicted value

Before surgery all patients reported to be more or less restricted in one or more areas, but three patients experienced one or more serious restrictions in their daily activities. Performance in daily life activities improved in three patients, remained more or less the same in two patients and one patient scored worse after six months. This patient had undergone a re-operation because a mesh had to be removed.

Data derived from the SF-36 health survey indicate that patients judged their situation identical in four out of eight categories preoperatively and 6 months postoperatively (Table IV). “Physical functioning”, “role functioning-physical” and “social functioning” showed minor improvement, and only “role functioning-emotional” had a worse outcome. In contrast, four out of six patients eventually scored their health as “much better now than one year ago”. One patient thought his health was “much worse than one year ago”, who appeared to be the patient who needed removal of his mesh.

Table IV. Outcome of Quality of Life assessed by SF-36 health survey

	Mean	
	Preop	**6 months**
Physical functioning	57	63
Role physical	29	38
Bodily pain	65	61
General health	63	60
Vitality	57	60
Social functioning	50	66
Role emotional	78	61
Mental health	75	71

The results for the 36 items have been transformed into 100-point scales for eight dimensions of well-being. One hundred represents best health and zero refers to no health.

Discussion

This first study investigating the lung and muscle function after Ramirez abdominoplasty suggests that application of the Component Separation Method (CSM) in the repair of large incisional hernias does not impair but possibly improves lung function on the long term. Furthermore, a tendency towards improved physical performance and a subjective increase of well-being was seen. Repair of abdominal wall defects generally is alleged to be accompanied by a decreased respiratory function.[8,9,16,17] In our experience however, respiratory function was not impaired after abdominal wall repair by means of the CSM.

Due to retraction of the lateral abdominal wall muscles, in patients with large abdominal wall defects, the original abdominal containment capacity is diminished, limiting the possibility of uneventful reduction of the hernial sac content, which frequently has lost its "right of domain". This hampered reduction and closure of the herniation, in addition to the often-unhealthy fascial edges, causes primary closure of these hernias to be ill advised. Restoring the complete musculoaponeurotic, dynamic coverage of the abdominal cavity however, can theoretically restore physical performance.

Earlier reports showed resolution of back pain as a result of reconstruction of a large abdominal wall defect.[6,7] Bridging the defect with any type of material does have the advantage of a garanteed undiminished abdominal containment capacity but does not restore its musculoaponeurotic, dynamic coverage. The CSM restores the musculoaponeurotic coverage of the abdomen and theoretically increases the abdominal containment capacity. We hypothesized that peroperative increase of the intra-abdominal capacity by executing the CSM, as a technique to close incisional hernias, will gain enough space to harbour the hernial sac content without subsequent impairment of the respiratory function on the long term. This pilot study in six patients so far supports our hypothesis as none of the patients showed a decrease in pulmonary function six months postoperatively, while two even showed an improvement. Only one patient showed direct postoperative respiratory insufficiency, which can be attributed to a period of circulatory instability requiring an aggressive fluid-infusion intra-operatively. Lung function obviously should also profit from restoration of the abdominal wall integrity, being able to counteract diaphragm movements and allowing “abdominal respiration”. So far this alleged positive role of a complete reconstruction of the anterior abdominal wall muscles lacked attention in literature. Given the preliminary results in our small series of selected patients we can not survey the ultimate role and importance of this contribution.

The assumption that reconstruction of the circumferential aponeurotic muscular coverage of the abdominal cavity would result in improved physical performance and higher score for activities in daily life was not found in every patient but a positive tendency was outlined. While one patient performed more or less the same after surgery, all others clearly improved at least in either sit-ups or leg-raises while four improved both. It is questionable whether this type of physical exercise is the most ideal way to test physical performance in patients with ventral hernias. Contrary to patients with groin hernias where this method has repeatedly shown to accurately determine physical performance, patients with large and often recurrent ventral hernias, physical performance-levels can be expected to be much lower due to limitations in daily life activities, as well as their emotional condition.[14] In an earlier study we discovered that a large amount of patients with large, often recurrent, abdominal wall defects have psychological counselling, possible due to the longevity of their illness, characterised by multiple operations and intensive care admissions.[18] However, in this preliminary study an indication is given that restoration of the muscular abdominal wall integrity might result in improved physical performance.

This minor, but objective improvement in physical performance was supported by the subjectively judged improved current health compared to the situation before the operation and the slightly improved outcome of the SF-36 score. Possibly the combination of unimpaired pulmonary function, loss of the visible bulge and slightly improved physical performance is responsible for the improved quality of life.

The number of patients is too small to produce statistically significant evidence in this preliminary prospective study although tendencies are outlined. Larger studies on the effect of applying the CSM to repair large ventral abdominal wall defects are warranted in which the increase in the abdominal containment capacity is correlated to pulmonary function and the content of the hernial sac. In this respect the effect of the restoration of the circumferential musculoaponeurotic coverage on pulmonary function and physical performance should also be investigated.

In conclusion this study shows that application of the CSM in large size incisional hernias does not impair postoperative pulmonary function, as well as physical performance, possibly due to the created increase of the abdominal containment capacity as well as restoration of the dynamic muscular integrity of the abdominal wall by means of this procedure.

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Chapter 7 - Impaired abdominal wall muscle perfusion resulting from raised intra-abdominal pressure during laparoscopic cholecystectomy

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Introduction

Adverse effects of elevated intra abdominal pressure (IAP) on the cardiovascular, respiratory and renal system are well described in literature.[1-5] Wound related complications after laparotomy (eg. fascial dehiscence) in patients with increased intra abdominal pressure, are also known, although the exact underlying mechanisms are still unclear. Adequate tissue perfusion is a prerequisite for any wound healing process and perfusion of the rectus abdominis muscle has shown to be impaired by high suture tension in animal experiments.[6] Sustained reduction of perfusion of the muscular components of the abdominal wall in the postoperative phase might therefore be an important factor in the origin of fascial dehiscence or incisional hernia formation in patients with increased IAP. Although one single animal study found a significant reduction in rectus sheath blood flow (RSBF) based on an elevated IAP, up till now no clinical study investigated this relationship in humans.[7]

In a healthy patient population planned for laparoscopic cholecystectomy, we investigated the relation between IAP and tissue perfusion in the rectus abdominis muscle, using a Licox® microcatheter probe for continous measurement of muscle pO_2.[8-11] To allow differentiation with other effects initiated by increased IAP, we took arterial blood samples and additionally measured intra-cystic pressure (ICP), gastric pCO_2 (g-pCO_2) with continuous monitoring of cardiac function by a transesophageal echocardiography-Doppler device (TEE).

Patients and methods

After approval by the institutional review board and Ethical Committee, the regional Ethical Committee (METC) as well as the Central Committee on Research Involving Human Subjects (CCMO), 10 patients were included, all with an American Society of Anesthesiologists physical status I or II (and without previous abdominal surgery) who were scheduled for laparoscopic cholecystectomy for symptomatic gallstone disease. Patients with a body mass index (BMI) > 30 or a history of bladder dysfunction, were excluded. Both patients and their General Practitioner were well informed and a signed informed consent was obtained from all patients. Eight females and two male patients were included in the study, a reflection of the regular population scheduled for (laparoscopic) cholecystecomy.

Anesthesia protocol

A standardized general anesthesia protocol was followed for all patients. In each operation, the same dedicated anaesthesiologist (experienced in using a TEE-Doppler device) induced total intravenous general anesthesia with target controlled infusion of propofol (4 ug/ml), remifentanyl (50 ug/kg/hr) for analgesia and rocuronium (0,6 mg/kg) to facilitate tracheal intubation and maintain muscle relaxation and ventilation with 100% oxygen in air (F_iO_2). Anesthesia was maintained with a target propofol concentration of 2,5 ug/ml and remifentanyl at 15 ug/kg/hr. Rocuronium (0,2 mg/kg) was administered every 30 minutes during the procedure. All patients were mechanically ventilated with a ventilator (Dräger Cato) at a tidal volume of 8 ml/kg/minute and with F_iO_2 of 40 % as soon as induction was completed. Ventilator settings were fixed, Positive End Expiratory Pressure was fixed at 5 mmHg and inhalational agents were omitted.

Measurements

Intraoperative monitoring included electrocardiography, pulse oximetry, mean arterial pressure (MAP), $ETCO_2$ (end-tidal partial CO_2 pressure) and blood samples were taken from a line in the radial artery at every pressure level. A tonometer (Datex-Ohmeda TONO-16F) was nasally inserted into the stomach to determine gastric pCO_2 (g-pCO_2) and its position was confirmed by auscultation and aspiration of bile.[12,13] Additionally, a TEE-Doppler probe (Dynemo 3100, Arrow International) with disposable sterile sheath was orally inserted. The TEE was placed at an optimal Doppler and ultrasound signal and fixed, facilitating beat-to-beat, real-time cardiac output (CO) and cardiac index (CI) measurement.[14-16] A Foley urine catheter was inserted and the bladder emptied. Two three-way stopcocks were serially connected to each other and the Foley catheter. A standard intravenous infusion set was connected to 100 ml of normal saline, which is injected into the bladder via one stopcock to create a conductive fluid column. This stopcock was then turned “off”. A disposable pressure transducer was connected to the other stopcock and zeroed at the level of the top of the symphysis pubis, for intra-cystic pressure measurement (ICP).

After induction of anesthesia, the operative field was desinfected and prepared for surgery. First, a small sub-xiphoïdal incision (1,5 cm) was made, at the location were a 12 mm trocar could be placed (after termination of all experimental measurements), so no additional incision had to be made for rectus perfusion measurement. This provided an “open access” and therefore confirmed placement of a Licox® oxygen micro probe (Φ = 0,5 mm, precalibrated, Integra Neurosciences). A pre-shaped (slightly curved) arterial needle with sheath, was inserted into the left rectus muscle. The needle was withdrawn and through the undisplaced sheath, the Licox® microcatheter was inserted, with the tip well under the anterior rectus sheath (> 2cm), and the arterial needle sheath meticulously withdrawn. Then the microprobe was connected to an oxygen monitor (Licox CMP®, Integra Neurosciences) and fixed with a clear sterile drape. Surgical technique was identical in all patients and laparoscopic equipment was calibrated before each operation. CO_2-insufflation was performed via a Veress-needle, increasing with 5 mmHg after each measuring period. All data were recorded at predetermined intervals with the patient in horizontal position. Ten minutes after placement of the Licox® microprobe (finally placed measuring device) the baseline measurements were taken, after which insufflation was started and adjusted at 5 mmHg. An equilibration period of 10 minutes was consequently used at every pressure level to accommodate the tonometer and Licox® microprobe before new data were collected. This procedure was continued until the level of 20 mmHg and after the last measurements were taken, the IAP level was returned to 14 mmHg. The laparoscopic cholecystectomy was performed routinely but in all cases the position of the Licox® microprobe (subxiphoïdal) was checked with the inserted laparoscope for accidental penetration of the posterior rectus sheath and peritoneum. After removal of the Licox® microprobe, other trocars were inserted and the operation was continued. At the end of the operation, the Foley catheter was removed and urinary output was documented.

All data were recorded at the same time points, with an equilibration period of

10 minutes after reaching the targeted intra-abdominal pressure level, and were imported in a spreadsheet on a notebook. Arterial blood gas analysis values were printed and added postoperatively. Overall statistical significance of changes in each measurement was assessed by Repeated Measurement Analysis.

Results

In 10 patients scheduled for laparoscopic cholecystectomy, with a mean age of 51 years (range 37 – 68) and a mean Body Mass Index of 26.6 (range 21 – 30), all experimental measurements were performed without adverse events or complications. Mean OR time was 126 minutes (range 100 – 160), including cholecystectomy, during which a mean volume of 2430 ml was administered intravenously (range 1000 – 3500).

Intra-cystic pressure (ICP)

Every patient showed a positive baseline ICP except for one and there was a wide range of baseline values. ICP showed an increase parallel to the raise of IAP but in one patient ICP measurement was consequently 5 mm Hg higher than the IAP. This patient also showed a remarkably high urinary output of 500 ml during the operation, while mean urinary output of all patients was 110 ml. This probably explains the higher values. We found a statistically significant positive correlation between the actual IAP and ICP ($p<0.001$, Table I).

Cardio-vascular parameters

A positive correlation was also found between IAP and Mean Arterial Pressure (MAP) and pulse-rate (Table II). Stroke Volume showed a negative correlation with IAP but this relation was not statistically significant. Due to the raised pulse rate, both CO and CI were only moderately decreased, as shown by the TEE-Doppler device.

Tissue perfusion

Gastric pCO_2 (g-pCO_2) was positively correlated to IAP and showed a gradual increase in time (Table I). Despite this increasing g-pCO_2, calculated pHi in gastric

Table I. Invasive measurements (n = 10)

	units	baseline	SD	IAP 5	SD	IAP 10	SD	IAP 15	SD	IAP 20	SD	p-value
ICP	mmHg	5,5	2,76	7,0	2,62	10,6	2,59	15,1	2,85	19,8	2,86	< 0.001*
g-pCO_2	mmHg	36,7	5,2	41,3	7,1	44,0	7,7	45,1	5,1	46,1	4,2	< 0.001*
pH_i		7,40	0,09	7,35	0,08	7,32	0,06	7,32	0,04	7,30	0,04	0.013*
rectus pCO_2	mmHg	57,87	21,16	58,55	21,50	56,65	24,76	55,34	25,28	50,45	22,13	0.015*

Data are mean values of all patients on every level of IAP (0 to 20)
IAP= Intra Abdominal Pressure in mmHg
ICP = Intra Cystic Pressure
pH_i = calculated gastric mucosal acidity
p-value = statistical significance (Greenhouse-Geisser test)
SD = Standard Deviation
g-pCO_2 = gastric mucosal carbon dioxide
rectus pO_2 = partial oxygen pressure in rectus muscle
* = statistically significant (p-value < 0.05)

Table II. Cardiovascular parameters related to IAP-levels (n = 10)

	units	baseline	SD	IAP 5	SD	IAP 10	SD	IAP 15	SD	IAP 20	SD	p-value
CO	L/min	4,17	1,28	4,21	0,82	4,27	0,72	4,14	0,89	3,99	0,90	0.780
CI	L/min/m²	2,20	0,50	2,28	0,24	2,23	0,21	2,16	0,39	2,04	0,48	0.344
SV	ml	0,068	0,02	0,066	0,02	0,063	0,02	0,059	0,02	0,056	0,01	0.080
SV_i	ml/ m²	0,04	0,01	0,04	0,01	0,03	0,01	0,03	0,01	0,03	0,01	0.066
MAP	mmHg	68,78	7,02	89,44	12,79	98,33	10,41	99,89	8,73	98,67	9,90	< 0.001*
pulse	/min	61,3	9,41	63,5	10,81	67,9	9,11	69,9	9,27	71,8	8,35	< 0.001*

Data are mean values of all patients on every level of IAP (0 to 20)
IAP= Intra Abdominal Pressure in mmHg
ICP = Intra Cystic Pressure
CI = Cardiac Index
SVi = Stroke Volume Index
p-value = statistical significance (Greenhouse-Geisser test)
SD = Standard Deviation
CO = Cardiac Output
SV = Stroke Volume
MAP = Mean Arterial Pressure
* = statistically significant (p-value < 0.05)

mucosa did not show significant acidosis. Rectus muscle pO_2 clearly showed a negative correlation with increasing IAP, being most obvious when progressing from 15 to 20 mmHg (9 % decrease of rectus pO_2, with a total decline of 13 %). Repeated measurement analysis revealed a statistically significant relation between the IAP and rectus muscle perfusion, by using the Greenhouse-Geisser-test (p=0.015).
With the availability of arterial pO_2, saturation, hemoglobine amount, CO and CI, oxygen content (CaO_2), oxygen delivery (DO_2) and oxygen delivery index (DO_2i) could be calculated (Table III). We found only minimal changes in CaO_2 , DO_2 or DO_2i based on elevation of IAP and these changes were not statistically significant.

Table III. Systemic oxygen content and oxygen delivery related to IAP-levels (n = 10)

	units	baseline	SD	IAP 5	SD	IAP 10	SD	IAP 15	SD	IAP 20	SD	p-value
CaO_2	ml O_2/100 ml	18,99	1,17	18,83	1,11	18,81	1,12	18,81	1,10	18,81	1,09	0.100
DO_2	ml/min	796,92	276,78	791,65	159,24	803,10	142,89	780,28	183,57	754,36	194,69	0.808
DO_{2i}	ml/min/m^2	420,70	119,58	451,95	77,74	442,53	76,86	426,44	103,85	413,07	119,08	0.656

Data are mean values of all patients on every level of IAP (0 – 20)
IAP= Intra Abdominal Pressure in mmHg SD = Standard Deviation
CaO_2 = Oxygen Content DO_2 = Oxygen Delivery
DO_{2i} = Oxygen Delivery Index
p-value = statistical significance (Greenhouse-Geisser test)
* = statistically significant (p-value < 0.05)

Blood gas values

During the measurements at initial pressure-levels we noted a drop in arterial pO_2 (Table IV). This decline was restricted to progressing from 0 to 10 mmHg and stabilized onward, possibly still decreasing from induction with 100 % oxygen, lowered to an F_iO_2 of 40% after completion. Arterial pCO_2 and $ETCO_2$ showed an increase in time and were positively correlated to actual IAP. This relation proved statistically significant (p<0.001).

Before removing the Licox® microprobe (subxiphoïdal), the position was checked in all patients for accidental penetration of the posterior rectus sheath and peritoneum, after insertion of the laparoscope. We did not find this is any of our patients.

Table IV. Blood gas values and end-tidal pCO_2 related to IAP-levels (n = 10)

	units	baseline	SD	IAP 5	SD	IAP 10	SD	IAP 15	SD	IAP 20	SD	p-value
$ETCO_2$	%	4,11	0,24	4,35	0,30	4,65	0,38	4,84	0,42	4,92	0,53	< 0.001*
pH		7,40	0,09	7,36	0,08	7,36	0,06	7,33	0,04	7,32	0,04	< 0.001*
pCO_2	mmHg	35,60	3,98	39,20	4,96	39,80	3,61	42,60	5,56	42,90	4,51	< 0.001*
pO_2	mmHg	244,70	116,35	191,60	47,88	187,40	44,26	185,90	44,96	185,90	45,08	0.100
bic	mmol/L	21,80	2,35	22,10	1,45	22,2	1,48	22,10	2,02	21,80	1,32	0.610
BE	mmol/L	-2,31	2,34	-2,96	1,90	-3,01	1,69	-3,47	2,18	-3,77	1,49	0.002*

Data are mean values of all patients on every level of IAP (0 – 20)
IAP= Intra Abdominal Pressure in mmHg SD = Standard Deviation
$ET\text{-}CO_2$ = End Tidal carbon dioxide pH = acidity
pCO_2 = partial carbon dioxide pressure pO_2 = partial oxide pressure
bic = bicarbonate content BE = Base Excess
p-value = statistical significance (Greenhouse-Geisser test) * = statistically significant (p-value < 0.05)

Discussion

Increased IAP can occur in various situations, for instance after blunt trauma (with intra-abdominal or retro-peritoneal bleeding), in case of bowel distension (visceral oedema or ileus), ascites, intra-abdominal packing or due to a pathological mass. However, not only changes in abdominal content but alterations in volume retaining capacity of the abdominal wall will also be of significant influence to the IAP. Reconstruction of a large abdominal wall defect will re-establish the so called “abdominal domain” which requires an increase of the intra-abdominal volume retaining capacity and by closure of the defect, abdominal wall compliance might be decreased.[17]
Direct measurement of IAP in patients is often not feasible and can be impractical. The best technique for indirect measurement of IAP is controversial but the revised method of intra-vesicular pressure measurement is a cost effective, quick and therefore most commonly used technique in daily practise.[18-21]
We confirmed a positive correlation between the ICP and IAP but found a higher baseline pressure in the bladder than in the abdomen. Intrinsic detrusor muscle activity can be stimulated by the amount, temperature and rate of infusion after instillation of fluid into the bladder.[22] This could explain higher baseline pressures in our patients, although the gradually infused saline was at body temperature and the bladder had just been emptied.

Respiratory, hemodynamic and renal problems related to elevated IAP are well described in literature, as well as the negative effects on intestinal blood flow.[1-5,23,24] Wound related problems are also frequently seen in patients with raised IAP after laparotomy, although the underlying mechanism is not yet revealed. Endogenous patient factors, as well as suture material and technique are important issues, but adequate blood supply and subsequent tissue perfusion are essential for every healing process in the human body.[25,26] Sustained reduction of tissue perfusion at the level of the rectus muscles, may therefore play an important role in failed wound healing (eg. wound infection, fascial dehiscence or incisional hernia) in patients with increased IAP. Most perfusion studies on the effects of elevated IAP are focussed on cranial or intestinal mucosal blood flow. From animal studies we know that increased IAP leads to a reduction in blood flow of all intra-abdominal organs (except the adrenal gland) which can not entirely be attributed to a decreased cardiac output.[23] It is therefore likely that the perfusion of the rectus abdominis muscles, being dependent of the epigastric vessels, situated against the inner part of these muscles, is also decreased in case of elevated IAP. Diebel[8] investigated the relation of raised IAP and rectus sheath blood flow (RSBF) by using laserdoppler flowmetry (LDF) in a porcine model. In seven domestic swine he discovered a significant negative correlation between RSBF and IAP with a decrease of RSBF to 58 and 45 % of the baseline value at an IAP of 10 and 20 mmHg respectively. Because oxygen tension or pH was not measured, “critical levels” of perfusion could not be determined. Hoër[6] investigated the effect of suture tension on abdominal wall blood flow in animals by means of laser-fluorescence-videography. He found a reduction in tissue perfusion of 70 % in the rectus muscle in case of laparotomy closure with high suture tension in rabbits. Peak suture tension was found 4 hours after laparotomy, recovering after 72 hours. Up to now, no human study has investigated the effects of elevated IAP on the muscular components of the abdominal wall, at the level of tissue perfusion. This clinical study shows that in humans, mean rectus pO_2 decreases with rising IAP and that this relation is statistically significant (p=0.015). Question is whether this decreased rectus pO_2 is the result of a respiratory or hemodynamic effect induced by laparoscopy with CO_2 insufflation, possibly creating an impaired (systemic) oxygen delivery.

In our study, mean arterial pressure (MAP) showed a positive correlation with IAP, which can be explained by an increased afterload. Stroke volume (SV) gradually decreased when IAP was raised to a total decline of 18 %. Due to the compensatory increase in pulse rate of 17 %, actual cardiac output (CO) and cardiac index (CI) were almost maintained. During CO_2 insufflation they only showed a minor, not statistically significant decline of 4 and 7 % respectively. This can be attributed to sympathetic activation resulting in an increase in heart rate, which compensates the simultaneous myocardial depression (decline in stroke volume).[24]

Our patients showed a mean total rise in $ETCO_2$ and pCO_2 of 19,7 % and 22,6 % respectively, with increasing IAP from baseline to 20 mmHg. A decrease in pH and increase of arterial pCO_2 due to resorption during laparoscopic procedures have been described extensively in literature.[27-29] However, pH showed a total decline of only 1% so no clinically significant acidosis was seen. Impaired rectus muscle perfusion can therefore not be explained by respiratory acidosis due to raised IAP.

Reduced systemic oxygen content, can theoretically be responsible for any tissue hypoxia and therefore explain the impaired rectus muscle pO_2. Our study shows that g-pCO_2 indeed gradually increases with elevated IAP, but calculated gastric pHi revealed no significant tissue acidosis as a result. Raising IAP up to 20 mmHg in healthy patients does not seem to create clinically relevant tissue acidosis in gastric mucosa. To investigate the role of oxygen content of the arterial blood, we calculated CaO_2 by using haemoglobin concentration, saturation and PaO_2. Because CO and CI were recorded, oxygen delivery and oxygen delivery index (DO_2 and DO_2i) could also be determined. No significant changes in CaO_2, DO_2 en DO_2i were found as a result of raised IAP so oxygen delivery does not seem to be a causative factor for impaired rectus pO_2.

As oxygen content and oxygen delivery of the arterial blood remain uninfluenced, and splanchnic tissue acidosis does not develop, impaired perfusion of the rectus muscles seems to be exclusively based on elevation of intra abdominal pressure. Local compression of epigastric arteries against the abdominal wall, resulting in a decreased flow to the muscular components, might be an explanation of these findings. Sustained elevated IAP increases suture tension and hypoperfusion of laparotomy wounds, which will result in impaired collagen deposition and increased neutrophil leucocyte infiltration around the sutures with subsequent lower breaking strength and a higher risk for wound infection.[6,25,26,30,31,32]

In conclusion we can say that it is therefore likely that prolonged raised IAP and subsequent impaired perfusion of the rectus muscles, is a risk factor for the development of incisional hernia. The technique of using an intra-muscular Lycox oxygen probe provides an objective and reproducible method to determine tissue oxygenation and the application might contribute to the prevention of incisional hernias in the future.

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Chapter 8 - Incisional hernia repair – abdominoplasty, tissue expansion and methods of augmentation

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Introduction

In general, two strategies exist for the treatment of abdominal wall defects that are not amenable to tensionless approximation of the natural tissues. The first option is to bridge the defect with the patients' own tissue, synthetic products or a composite material and the second option is to reapproximate the natural tissue after utilising relaxing incisions or preoperative measures such as tissue-expansion or progressive pneumoperitoneum.[1]

The aim should be full restoration of abdominal wall function to include muscular support, prevention of visceral eventration and adequate soft tissue coverage. It is unclear whether complete circumferential musculofascial integrity of the abdominal wall is mandatory for this purpose. At the present time there are no criteria to assist in the selection of which method to adopt, although some authors have formulated recommendations. In this review the results of different types of abdominoplasty for bridging abdominal wall defects are described as well as our own and others' results with tissue expansion. Finally our series of augmented closures of large abdominal wall defects is reported.

Bridging abdominal wall defects using abdominoplasty

Remote cutaneous, fascial and muscular tissues of the patient can be used for bridging an abdominal wall defect. Typically, cutaneous flaps attached to fascia or muscle and fed by one major artery, or transposed muscular flaps have been described in the literature with various results.[2-10]

Local muscle flaps for bridging smaller defects include the transposition of the rectus abdominis, external oblique or internal oblique muscle of which the rectus is most often used.[11] Generally the results are not encouraging either due to problems at the donor-site or the need for additional synthetic support of the reconstruction.

Larger defects can be covered with distant flaps. Wagensteen[3] first described the Tensor Fascia Lata (TFL) flap in 1946 for coverage of lower abdominal wall defects. The TFL can be used as a simple fascial graft, pedicled rotation flap or as a free flap (microsurgical transfer). Traditional drawbacks of a pedicled rotation flap

are the uncertanty about the blood supply to the distal third of the fascia, the limited arc of rotation and the fact that the bulk of the flap consists of non-dynamic fascia.[6,7] This can result in a high recurrence rate (42%) and flap necrosis (20%).
Using a free flap can overcome the limited rotation and possibly ischemic complications. Kuo[12] successfully used a free anterolateral thigh flap with fascia lata in seven patients with large full thickness abdominal wall defects and reported no recurrences. Although functional evaluation of the quadriceps muscle showed an average deficit of 30 % as compared to the other side, no restrictions in daily activities were reported. Williams[13] however treated seven patients with a free TFL flap and reported necrosis of the distal tip in four cases.

Another frequently used technique is the Rectus Femoris Flap (RFF), first described by McCraw[7] in 1977. He not only described the individual territories but also the limitations of various myocutaneous flaps. He underlined that shrinkage of the muscular component of any flap can reach more than 50% due to detachment and denervation of the muscle.
In contrast to rotation of the TFL on its pedicle, it is possible to turn the RFF on itself to cover upper abdominal wall defects. The disadvantage however, is donor site morbidity especially muscle weakness during the last 10 - 15 degrees of knee extension.[9] Brown[5] overcame this functional deficit after bilateral pedicled RFF by approximation of the vastus medialis and lateralis, in order to replace the lost rectus femoris physiologically.
The latissimus dorsi is another highly suitable muscle for closure of defects mainly of the upper third of the abdominal wall and is usually associated with a low complication rate, however donor-site morbidity again forms an important limitation.[11]

Closure of abdominal wall defects after progressive preoperative pneumoperitoneum

Artificial progressive pneumoperitoneum as preoperative preparation for closure of abdominal wall defects has existed for 60 years. Most publications are small case studies or anecdotal case-reports.[14] Alleged advantages of this method are tensionless closure of the abdominal wall with natural tissue, preoperative lysis of intraabdominal and hernia-ring adhesions, improvement of the diaphragmatic function, decreased chronic mesenteric edema, volume reduction of hollow organs and detection of additional areas of fascial weakness.[15]

Indications: The purpose of this technique is to achieve closure of the abdominal wall by approximation of the medial borders of the rectus muscles. The most important stated criterion for the use of this technique is the presence of "loss of domain" in which some of the intraabdominal organs in a hernial sac form a "second abdominal cavity" and complete reduction of the hernial contents is impossible regardless of the size of the defect.[16] In this situation reduction of the hernial contents without some modification of the size of the abdominal cavity can result in abdominal compartment syndrome.

Technique: The physiological basis of the technique is that gradual stretching of the abdominal muscles will increase the abdominal volume and restore muscle function. Air is insufflated intraperitoneally at regular intervals either via intermittent percutaneous puncture of the abdominal wall or an indwelling intraabdominal catheter.[17] Preferably the site of placement of this catheter should be at a distance from the hernia and previous incisions, which is usually achieved by puncturing in the left lower quadrant.[18,19] A total of 15 to 20 litres is insufflated over a period of 3 to 6 weeks which should result in gradual stretching of the abdominal wall and physiologic adaptation of the various organ systems. An important indication for termination of the pre-treatment is bulging of the flanks which is an external sign of significant stretch of the abdominal cavity. From a theoretical, physical standpoint Laplace's law predicts a homogenous distention of the abdominal wall including the hernial sac. In practice it is claimed that this does not occur because of the difference in compliance between the hernial sac and the abdominal wall.[16] Data are lacking but dense adhesions at the hernial ring might result in differential distribution of air and pressure between the abdominal cavity and hernial sac.

Results: Long-term results and controlled comparisons are lacking mostly due to the large interindividual differences in size and site of the defects in reported series. Murr[20] described 27 patients operated on in a 40-year period with a recurrence rate of 18.2% which is in contrast to most other reports that show lower recurrence rates. For example Toniato[21] treated 77 patients and achieved a success-rate of 97.4%.

In many of his cases a mesh was used to augment the repair. Possible complications are subcutaneous emphysema or hematoma due to repetitive punctures.[22,23] *Conclusion:* Few advances have been made in the application of this technique since the last report on pneumoperitineum in this journal, mainly due to the failure of adoption by most clinicians. Contributions that may increase adoption include the increase in the variety and property of meshes available and the introduction of laparoscopic repair techniques which ironically could not exist without intraoperative pneumoperitoneum. Therefore the conclusion that progressive preoperative pneumoperitoneum is a useful adjunct in the treatment of large abdominal wall defects remains unchanged.[18]

Closure of abdominal wall defects after tissue expansion

Introduction: Expansion of musculofascial tissue, using temporarily implanted expanders as a precursor to reconstruction of abdominal wall was first described by Byrd and Hobar[24] for congenital defects and later by the same group for posttraumatic defects. Gradual expansion should provide autogenous, innervated and healthy tissue allowing reapproximation of the natural tissue. Possible locations for the expanders are: subcutaneous, between external and internal oblique muscles, intramuscular between internal oblique and transverse abdominus and finally intraabdominally. The latter is described in two anecdotal reports in which pregnancy was an autologous tissue expander, allowing closure of a 15x8 cm and 20x30 cm size tissue-defect. However, one of these defects recurred after a follow-up period of less than one year.[25,26] The role of pregnancy hormones in this gradual and infection-free method is unclear and the application rather limited.
Results: In all cases tailor-made expanders are implanted and gradually inflated in various time-schedules. Subcutaneous placement under healthy skin gains sufficient skin and subcutis to be approximated. For example, this can be done over a denuded skingraft that covered a laparostomy; not achieving a reconstruction but soft tissue bridging of the original abdominal wall.[27] Carlson[28] describes the same procedure combined with a modified “Stoppa”-repair with a polyester-mesh being in direct contact with the viscera and then covered with the expanded dermal tissue. A mean follow-up period of 14 months showed successful “closure” in all

cases. Similar results are demonstrated by Paletta[29] in 11 patients after a 2-5 years period. From an anatomical point of view placing expanders in the plane between transverse and internal oblique muscle appears ill-advised due to the fact that this area contains the nervous and arterial supply for these two muscles and the rectus. Nevertheless Hobar[24] described using this plane successfully in one patient with two large defects in the midline and achieved persistent good function of the closed abdominal wall up to 4 years postoperatively. Ramirez[30] reported his Component Separation Method (CSM) in 1990, indicating that the plane between the external oblique and the internal oblique essentially is bloodless and nerveless rendering it the most suitable plane for separation of the lateral abdominal wall muscles and into which tissue-expanders can also be placed. In one of our own patients this plane was used for tissue-expansion in the successful reconstruction of an abdominal wall defect of just 8 cm in diameter but with half of the abdominal contents having resided subcutaneously for more than 10 years. The expanders were implanted via separate incisions in a bluntly developed pocket in the plane between external and internal oblique. During a three week period the expanders were gradually insufflated depending on the patient's sensation of discomfort, with aliquots of between 40 and 120 ml of saline. The expanders were removed during the operation for definitive closure of the defect. After 24 months the patient showed no signs of recurrence, ulceration or fistulation. Jacobsen[31] supported our findings with their success in four patients treated in a similar manner.

Discussion: Controlled trials concerning the use of tissue expansion for closing abdominal wall defects do not exist. From an anatomical point of view the plane between the external oblique and internal oblique muscles seems to be the most convenient to use. It is a time-consuming and expensive therapy as the process of gradual expansion takes several weeks and the expanders need to be tailor-made. Furthermore there may be doubts about its theoretic effectiveness because the application of Laplace's law during expansion includes not only separation of the two muscles but also compression of the current intraabdominal volume resulting in a limited enlargement of the structures needed. This might be reflected by the 29% recurrence rate in 31 patients treated by Tran.[32] Subcutaneous tissue expansion does not result in any alteration to the structure of the musculofascial abdominal wall but can serve as an adjunct to bridge these defects.

Augmented (mesh) closure of abdominal wall defects

Increased understanding and correct application of prosthetic mesh has reduced recurrence rates during recent years after reconstruction of large abdominal wall defects . However, one of the most frequently reported complications following open mesh incisional hernia repair is seroma formation (1 – 15%) which can result in significant morbidity.[33] The severity of the inflammatory response and tendency to seroma formation are thought to be dependent on the physical structure and quantity of prosthetic material, the need for extensive subcutaneous undermining and the positioning of the mesh.[34-36]

Intra-abdominal mesh

One solution for a possible reduction in seroma formation is the Intra Peritoneal Onlay Mesh technique (IPOM). In this case the hernial sac prevents contact between the mesh and subcutaneous tissue potentially lessening the risk of seroma formation. However, controlled studies are lacking to support this hypothesis. A potentially serious disadvantage of this technique is the direct contact of the mesh and the bowel which can result in adhesion formation (with the risk for strangulation) and fistulation. Although these initial concerns are subsiding, discussion on this topic still continues.[37,38]

Sublay mesh with musculocutaneous flaps

Combining prosthetic bridging with the use of a musculocutaneous flap can theoretically overcome the problem of seroma formation. Mathes[39] combined a sublay (retromuscular) prosthetic treatment with distant flap reconstruction in 9 patients because of unstable or absent skin coverage of the abdominal wall defect (so called type II patients). He found major complications in 17% of cases due to infection, skin or distal flap necrosis, or donor site related problems that needed reoperation, but recorded no recurrences after an average follow up of 14 months.Comparison with non-augmented reconstructions was not valid because the evaluation was mostly applied to patients with adequate skin coverage (so called type I patients) however, 3 out of 42 type II patients reconstructed with a musculocutaneous flap alone developed a recurrence.

"Wrapover plasty" and onlay mesh

Introduced and advocated by Chevrel[40,41] , the so called rectus "wrapover plasty" uses the dissected anterior rectus sheath bilaterally after lateral longitudinal incision and rotation into in the midline with suture closure to reconstruct a linea alba. Additionally a non-absorbable onlay mesh (Mersilene® or Prolene®) is fixed with absorbable sutures thereby broadly covering both rectus muscles. Fibrin glue is sprayed directly on the mesh to consolidate fixation to the underlying rectus muscles. This technique requires primary close of the rectus muscles in the midline, either after duplication of the anterior rectus sheath or after multiple relaxing incisions (e.g. Gibson or Clotteau-Prémont). Chevrel has reported a series of 389 patients with incisional hernias and found an 11% morbidity rate and only 5 recurrences at long term follow up. Various techniques were used in this series (only 20 "wrapover plasties") thereby making comparison with other studies difficult.

Retromuscular, prefascial (sublay) mesh with tension relaxing procedure (CSM)

Another ideal solution for closure of large (recurrent) abdominal wall defects is the use of autologous tissue (dynamic), after a tension relaxing procedure i.e. Components Separation Method (CSM) with the adjunct of prosthetic mesh in the prefascial, retromuscular space. We report our personal experience during the last 5 years with this type of augmented abdominal wall closure.

Patients: From 1996 to 2001 we treated 26 patients with a mean abdominal wall defect of 225 cm^2 and a median age of 58 (34-80). Median BMI was 29 (20-38) and two patients showed preoperative signs of enterocutaneous fistulation.

Method: All patients were treated with the CSM under antibiotic prophylaxis in a median operation time of 115 minutes with an average blood loss of 440 ml. Reconstruction was augmented by non resorbable prosthetic mesh (18 Mersilene®, 6 Prolene®, and 2 Marlex®) in the prefascial retromuscular space, fixed with polydioxanone-S sutures (Figure I). During 5 operations we found NRC-III contamination due to enterocutaneous fistulation (n=3) and bowel perforations with spill (n=2). For comparison we studied a cohort of our patients who during the same period had not received an augmented CSM reconstruction (n=69). This group showed similar patient characteristics except in 29 operations NRC-III contamination was encountered and the median total blood loss was 150 ml higher (Table I). The decision as to whether mesh augmentation was used was strictly at random because patients participated in different randomized trials. We performed postoperative physical examinations on all patients in the outpatient clinic.

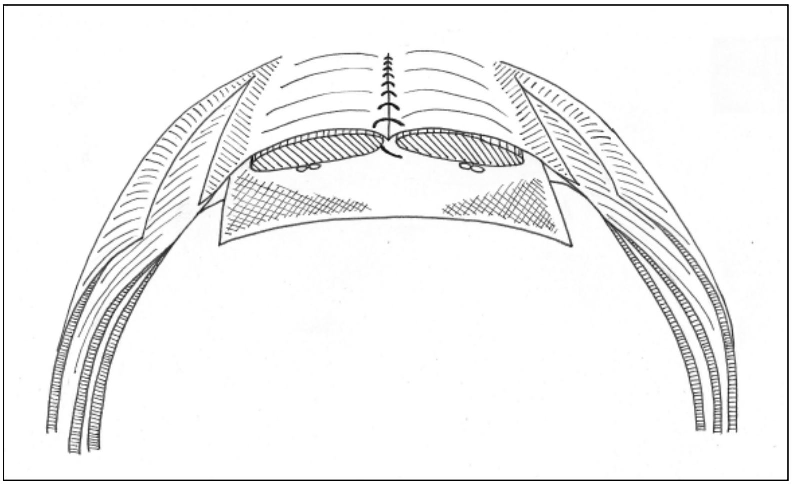

Figure I

Results: During a median length of stay of 10 days (3-60), 10 patients showed one or more complications. These were 7 superficial wound infections, 4 seromas and 1 case of pneumonia. Only one of 5 contaminated procedures was complicated by a wound infection. After a median follow-up period of 37 months (3-92) we found 1 small asymptomatic recurrence in the group with mesh augmentation (3.8%) versus 12 in patients without augmentation (17%). These 12 patients were equally divided between contaminated and non contaminated groups (both groups had 6 recurrences).

Table I. Patient characteristics (mesh vs non-mesh)

n=95	n	m / f	age	BMI	size	time	TBL	contam.	WI	seroma	recurr.
CSM + augm.	26	13/13	58	28,8	225,0 (SD 126,9)	115 (SD 29)	500 (SD 223)	5 (19%)	7	4	1 (4%)
CSM	69	36/33	52	26,8	251,3 (SD 209,1)	120 (SD 43)	650 (SD 608)	29 (42%)	17	19	12 (17%)

CSM	Components Separation Method	m / f	male / female
age	mean age (years)	BMI	median Body Mass Index
size	mean defect size in cm^2	time	median operation time (minutes)
TBL	median total blood loss (ml)	contam.	number of contaminated procedures
WI	number of woundinfections	recurr.	number of recurrences
SD	Standard Deviation	augm.	augmentation with mesh.

Conclusions: Abdominal wall closure using the Components Separation Method augmented by non absorbable mesh provides favourable long term results, compared with a cohort of our patients treated with a non-augmented CSM-closure. Combining the benefits of autologue tissue use and mesh augmentation results in a very low recurrence rate. The higher recurrence rate in patients without mesh augmentation cannot be attributed to the increased number of contaminated procedures.

The formation of seroma was not confined to patients in whom prosthetic mesh was used and this phenomenon may be the result of the need to dissect large subcutaneous flaps during the CSM technique. Minimally invasive dissection might reduce the amount of seroma and should be investigated in the future.[42,43]

Conclusions

The treatment of large abdominal wall defects is not yet standardized. This is not surprising as there are so many variables which have to be respected including etiology, size and site of the defect, duration of existence and idiosyncrazies of the patient, making controlled studies almost impossible. Moreover, at the present time there is not even a consensus on the definition of a “large abdominal wall defect”.[44] Therefore we should have no illusions about the creation of a classification-system with a subsequent algorithm determining the optimal management for each patient. No fundamental research has been done to investigate whether large abdominal wall defects should be bridged or an attempt should be made to reconstruct the circumferential muscular abdominal wall to restore optimal functiont. Some clinical situations preclude this ultimate goal such as cutaneous coverage of a laparostomy. It therefore may not be possible to find an optimal treatment strategy for all cases and each abdominal wall defect should be approached individually. Although multiple strategies are advocated, even for different situations, it requires careful planning to determine the optimal choice in each case. The first choice to be made is whether to treat the defect by bridging or closure. If the decision is to bridge it is achieved by utilizing the patients' own tissues or prosthetic material. The patients' own tissue is of limited stock, requires complex surgical skills and incurs additional donor site morbidity.[32] Tissue expansion clearly has advantages if only restoration of the abdominal skin coverage is attempted. Intaabdominal increase in volume can be achieved by both tissue expanders and progressive pneumoperitoneum but the techniques are expensive and time-consuming and have not shown individual superiority in a clinical trial. Combining these methods might be beneficial but again require further investigations. The results of our augmented CSM repairs are promising and are supported by Admire[44] who combined the CSM with tissue expansion. However, none of the forementioned repairs of large abdominal wall defects have been studied in acceptable trials. It is doubtful whether the great variations in pathology and the wide spectrum of therapies will allow large trials to prove the superiority of one of the techniques over another. Nevertheless surgeons interested in the repair of these defects should be encouraged to work together and to initiate trials to provide us with fundamental clues in order to offer patients a positive view of the results of each reconstructive operation.

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Chapter 9 - Summary and conclusions

Introduction

An incisional hernia remains one of the most frequent complications after laparotomy and holds an established position in every general surgeon's practice. Incisional hernias are late complications, as they develop long after completion of the initial tissue healing process with 50% presenting after 12 months and more than 10% after a postoperative period of 5 years.[1,2] As a consequence, the reported incidence of incisional hernia formation is largely underestimated, as most studies restrict follow-up to a period of 24 – 36 months. Studies with long term follow up show hernia rates up to almost 20 % after midline laparotomy.[1,3] In the Netherlands, more than 100.000 laparotomies are performed annually, indicating that more than 10.000 patients will develop an incisional hernia each year. In Germany and the United States, this last number exceeds 120.000 and 400.000 respectively.[4]
Abdominal wall reconstruction for hernia repair provides no guarantee for success, regarding the possibility of a recurrence. Especially for large size Abdominal Wall Defects (AWD), adequate coverage of the defect is technically not within easy reach and long term results are often disappointing. Direct suture repair will eventually result in recurrence rates varying from 37% to 63 % and with the use of mesh, recurrence rates up to 44 % are found.[4-8]
In addition, morbidity may be high, life threatening complications can arise and both functional and cosmetic results are sometimes disappointing. The high prevalence and related morbidity after incisional hernia repair result in tremendous costs and explain the considerable socio-economic burden associated with this pathology. This community-level impact is enlarged by the fact that patients are often unfit to work for a prolonged period of time and the re-operation rate is considerable.[9]
Therefore, we are still in search for a surgical technique with less recurrences, good functional results and the ability to restore quality of life, which is often impaired in these patients.

Summary of this thesis

In general, two strategies exist for the treatment of abdominal wall defects that are not amenable to tensionless approximation of the natural tissues. The first option is to bridge the defect with the patients' own tissue or prosthetic material. The second option is a modified closure technique: re-approximation of the fascial borders by using a tension relaxing procedure as the Components Separation Method (CSM), first described by Oscar Ramirez in 1990.[10]

Introduction of prosthetic material lowered the recurrence rate of incisional hernia repairs but was also accompanied by specific complications.[11,12] Despite these drawbacks, mesh repair seems the easiest and generally applicable procedure. This is probably the reason why non-mesh, tension relaxing closure techniques have become less popular and, in our opinion, underestimated during the last decades. The CSM is a tension reducing technique for closure of a large AWD by using the patients own tissue and hereby reconstructing the circular muscular integrity, resulting in a dynamic reconstruction of the abdominal wall. With this technique skin and subcutaneous tissue are mobilised bilaterally and the aponeurosis of the external oblique muscle is incised pararectally, about 1 cm lateral to the rectus muscle. The avascular plane between the external and internal oblique muscles can be separated easily by blunt dissection. This mobilisation is carried out as far as the posterior axillairy line. Furthermore, the rectus muscles are manually separated from its incasement in the posterior rectus sheath, in order to create additional translation. According to Ramirez' cadaver study, a total advancement to the midline of 5, 10 and 3 centimeters on either side in the epigastric, umbilical and suprapubic region respectively, can be realised.

Central questions of this thesis were:

- can the CSM really facilitate closure of large Abdominal Wall Defects?
- what is the mechanism behind this technique?
- what are the results of the CSM on the long term?
- is additional mesh augmentation of the CSM beneficial?
- can the CSM be used in contaminated situations?
- can we develop a reproducible method to document the influence of hernia closure on rectus muscle perfusion?
- what is the current position of the CSM in surgical repairs for AWD's?

Despite this limited appreciation and the lack of global adoption in surgery, the Components Separation Method has maintained an established position in abdominal wall reconstruction in specialized centres. Based on the potential benefits and its unfamiliarity among surgeons, we elaborated on all attendant factors involved in abdominal wall reconstruction by means of the CSM, according to our personal experience (**chapter 2).** In principal, all patients with large mid-line abdominal wall defects (> 5cm in width and a size > 50 cm^2) in combination with debilitating symptoms or local conditions urging intervention, are considered potential candidates for this technique. Pitfalls during the CSM are too wide an excision of the overlying skin, too superficial subcutaneous dissection resulting in endangered vascularisation of the skin, accidental simultaneous incision of the internal oblique muscles, no mesh augmentation in case of suboptimal tension reduction, inadequate mesh sublay underneath bony borders (sub-xiphoidal, retro-pubic) and disrespect for the suture length : wound length ratio (SL : WL ratio). We always close laparotomy wounds according the principle of SL : WL > 4, as reported by Israellson.[13]

In **chapter 3** we investigated the mechanical and anatomical changes of the abdominal wall muscles as a result of the CSM in a human cadaver model. By performing a standardized medial traction to the rectus muscles, before and after completing the CSM in 8 human cadavers, we were able to document a unilateral medial translation of 27, 45 and 40 mm at the level of xiphoid, umbilicus and Anterior Superior Iliac Spine (ASIS) respectively, allowing primary closure of fascial defects of 5.4, 9.0 and 8.0 cm width at these levels. Release of the external oblique muscle produced more benefit than release of the posterior rectus sheath. Our hypothesis of medio-caudal rotation around the centre of origin of the internal- and transverse oblique muscles, could not be confirmed, as we found this in only one cadaver. Although the responsible mechanism could no be explained, the limited relevance of mobilisation of the posterior rectus sheath in the CSM was evidently shown.

In **chapter 4** we described our long-term results of patients with large abdominal wall defects (AWD), reconstructed by means of the CSM with special interest in recurrences, daily life activities and the influence of mesh-augmentation. In a six year period we treated 95 patients with large AWD's. Wound related complications were frequently encountered with wound infection in 24 cases. After a median follow up period of 4 years, we found 15 patients with a recurrence (15.7 %), of whom 13 were asymptomatic and fully satisfied with their physical situation. In 26 patients with mesh augmentation, we found one small asymptomatic recurrence (3.8 %), about 2 cm below the xiphoid. In contrast, we found 14 recurrences (20 %) in 69 patients without mesh augmentation. Using the Fisher's exact test, a statistically significant difference was found between patients treated with and without mesh augmentation, regarding the recurrence-rate after 4 years ($p = 0.036$).
Most patients were able to perform all daily life activities without limitations. Twenty-two patients were limited in heavy weight bearing and 12 patients had problems with tying their shoe-laces. These complaints were unrelated to the additional use of prosthetic mesh. We concluded that the addition of mesh augmentation to the CSM, seems to reduce the recurrence-rate without creating more limitations in daily life. These results support our belief that mesh augmentation of the CSM gives better results on the long term.

Surgical repair of large and contaminated AWD's is a difficult problem. Because of the alleged high infection risk, patients are often treated in a multi-staged fashion. [14-18] As prosthetic mesh must often be used for reconstruction and the application of mesh in a contaminated wound will generally lead to deep wound infection, refuge is often taken with a multi stage repair, consisting of temporary coverage of the defect with prosthetic mesh, followed by split skin grafting and finally mesh excision and

definitive closure. Unfortunately this technique is not only time consuming, but is also accompanied by significant morbidity. The final stage of definitive closure will therefore not be accomplished in many patients.[14,16]
Straightforward suture repair is not only an attractive alternative but sometimes a one-stage procedure is the only available option. To emphasize the applicability of the CSM in contaminated situations we described our results in **chapter 5** with 26 patients in whom abdominal wall reconstruction was contaminated. In four patients we additionally used synthetic mesh for augmentation despite contamination because tension reduction after performing the CSM was not enough. Two thirds of our population (n=16) suffered from one or more postoperative complication, with wound infection being the most frequent (n=5). Surprisingly, we did not find an adverse relationship between the use of a non-absorbable mesh in the presence of contamination and wound infections as none of the four patients with mesh-augmentation showed wound-related problems. After a median follow-up of 27 months we found 2 patients with a small asymptomatic recurrence, which didn't need repair. Both patients had been treated without mesh augmentation.
Our results show that large contaminated abdominal wall defects can be closed successfully in a one-stage procedure, using the Components Separation Method but considerable morbidity is to be expected. Based on our experience in a small number of only 4 patients, we conclude that the presence of contamination does not exclude the use of synthetic mesh for augmentation.

One of the main functions of the abdominal wall is counteracting the force of the diaphragm during forced expiration. In patients with a large AWD, this supportive function consequently is impaired and 'abdominal respiration' is often impossible. Therefore respiratory function is expected to be limited, although research is lacking on this specific topic. By reconstructing an AWD, the intra-abdominal content usually increases by reduction of the hernia-content, with equal or even decreased containment capacity of the abdomen. As a consequence, an involuntary movement of the diaphragm in an upward direction is created, decreasing pulmonary compliance. Increasing the containment capacity of the abdomen is therefore a prerequisite, to prevent a decrease in pulmonary compliance after reduction of hernia-content and abdominal wall reconstruction. Closure of a large abdominal wall defect with the

CSM can theoretically improve postoperative pulmonary function because abdominal breathing is restored and the containment capacity of the abdomen increased, allowing the abdominal content to regain it's domain without excessive restriction of the intra-thoracic volume.

Many patients with a large abdominal wall defect complain of chronic back pain. Repair of a large abdominal wall defect can have a positive effect on these complaints and subsequently on the quality of life.[19]

In **chapter 6** we prospectively investigated the effects of the CSM on quality of life as well as on pulmonary- and abdominal wall muscle function in a pilot-study in 6 patients. All patients had a minimum age of 18 years, a large midline abdominal wall defect surrounding the umbilical area, no obstructive lung disease (GOLD IIb or higher), no previous fistulations, ostomies or other rectus muscle damaging (and quality of life influencing) procedures and not requiring emergency surgery or simultaneous reconstruction of the gastrointestinal tract. By comparing preoperative quality of life (SF-36), lung function (spirometry) and abdominal wall muscle function (sit-ups and straight leg raises) with the situation 6 months postoperatively, we found that the CSM does not impair pulmonary function, subjectively improves quality of life and objectively improves physical performance.

Wound related complications and fascial dehiscence are common in patients with raised intra abdominal pressure after laparotomy. Excessively tight sutures have shown to produce neutrophil accumulation around these sutures, collagenolysis and ischemic necrosis, leading to fascial dehiscence.[20,21,22] Tissue healing in general is largely dependant on adequate tissue perfusion. Collagen deposition and tensile strength of a wound is limited by impaired perfusion and tissue oxygen tension.[23] Prolonged reduction of perfusion of the muscular components of the abdominal wall might therefore be decisive for development of a weakened scar and promote formation of an incisional hernia.

We investigated perfusion of the rectus muscle in relation to a standardized elevated intra abdominal pressure and described our results **Chapter 7**. This is actually the first study to document this relationship in humans. We found a significantly impaired rectus muscle perfusion when IAP was raised up to 20 mmHg. A Lycox oxygen probe, directly placed intramuscular, seems a useful method to measure changes in tissue perfusion of the abdominal wall muscles in hemodynamic stable patients with an elevated IAP. As systemic oxygen content was unaffected, oxygen delivery not decreased and clinically significant systemic acidosis did not develop, secondary cardio-respiratory effects from raised IAP can not be held responsible for the specifically impaired rectus muscle perfusion which therefore seems solely based on the elevated IAP.

Several authors have tried to create a classification system applicable to all patients with abdominal wall defects. Curiously, there is no consensus on the definition of different types of hernia and moreover no criteria exist on which method should be used for reconstruction of a given AWD. In **chapter 8** we have reviewed all available methods of abdominal reconstruction based on literature and personal results. We concluded that no research has been performed, trying to clarify the fundamental dilemma whether to bridge a fascial defect or directly reconstruct the circular muscular integrity of the abdominal wall. From all described techniques, progressive preoperative pneumoperitoneum is not used very often but still remains a sometimes useful adjunct to current techniques. Tissue expansion is time consuming, requires custom made (expensive) tissue expanders and tissues expand not always in the preferred direction, resulting in limited profit.
Our results with the CSM combined with mesh augmentation are promising, considering all augmented (mesh) closure techniques. The additional use of synthetic mesh has shown to be beneficial, as it seems to result in less recurrences without creating more limitations in daily life. So far, none of the techniques for the repair of AWD's has been investigated in a decent randomized controlled trial with long term follow up. Given the enormous variation in pathology and possible treatment strategies, it is an illusion to assume that large randomized controlled trials will ever be conducted to proof superiority of one technique.

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Chapter 10 - Nederlandse Samenvatting

Introductie

Een littekenbreuk is één van de meest frequente complicaties na een laparotomie. Het betreft een late complicatie die zich lang na de initiële wondgenezing kan openbaren zodat 50 % van de littekenbreuken na 12 maanden en 10 % pas na 5 jaar wordt gevonden.[1,2] De incidentie van een littekenbreuk wordt hierdoor vaak onderschat, aangezien in veel studies de follow-up beperkt is tot 24-36 maanden. Studies met langdurige follow-up rapporteren een incidentie van 20 % na een laparotomie.[1-3] In Nederland worden jaarlijks meer dan 100.000 laparotomieën uitgevoerd zodat ruim 10.000 patiënten jaarlijks een littekenbreuk zullen ontwikkelen. In Duitsland en de Verenigde Staten zal dit aantal oplopen tot respectievelijk 120.000 en 400.000 per jaar.[4]

Buikwandreconstructie ter behandeling van een littekenbreuk is niet verzekerd van succes op termijn, gezien de recidiefkans. Met name in geval van grote buikwanddefecten is een adequate weke delen bedekking niet gemakkelijk haalbaar en zijn de lange termijn resultaten vaak teleurstellend. Het primair sluiten van een littekenbreuk resulteert in een recidiefpercentage variërend van 37 tot 63 % en na gebruik van een kunststof mesh kan dit oplopen tot 44 %.[4-8]

Daarnaast wordt de correctie van grote littekenbreuken gekenmerkt door een hoge morbiditeit, kunnen potentieel levensbedreigende complicaties optreden en zijn zowel de functionele als cosmetische resultaten niet altijd bevredigend. De combinatie van de hoge prevalentie van littekenbreukoperaties met gepaard gaande morbiditeit, de vaak langdurige arbeidsongeschiktheid en het aanzienlijke recidiefpercentage resulteren in hoge kosten en verklaren het enorme sociaal economische belang van deze aandoening.[9] Vandaar dat er nog altijd gezocht wordt naar een chirurgische techniek met minder recidieven en goede functionele resultaten, wat zou kunnen leiden tot een betere kwaliteit van leven.

Samenvatting

Globaal bestaan er twee strategieën voor de behandeling van patiënten met grote buikwanddefecten die niet spanningsloos gesloten kunnen worden. Ten eerste kan het defect overbrugd worden ('bridging') door middel van lichaamseigen of prothetisch materiaal (mesh). Als tweede mogelijkheid kan een gemodificeerde sluiting ('closing') worden toegepast door het (re)approximeren van de fascieranden nadat een ingreep is toegepast om de spanning op deze fascieranden te verminderen. De Componenten Separatie Methode (CSM) is zo'n methode die in 1990 door Oscar Ramirez is beschreven.[10]

De introductie van prothetisch materiaal voor herstel van buikwandherniaties heeft het recidiefpercentage verminderd, maar dit ging gepaard met specifieke klinische problemen en complicaties.[11,12] Ondanks deze nadelen lijkt herstel met behulp van een mesh het meest eenvoudig, waardoor een overbruggende techniek met synthetisch materiaal het meest frequent wordt toegepast voor deze indicatie. Dit is waarschijnlijk ook de reden waarom de spanningsverminderende technieken voor het primair sluiten van het defect de laatste decennia aan populariteit hebben ingeboet en worden onderschat.

De CSM is een spanningsverminderende operatie voor het sluiten van omvangrijke buikwanddefecten met behulp van lichaamseigen materiaal waarbij tevens de circumferentiële continuïteit van de buikspierwand wordt hersteld, resulterend in een dynamische reconstructie van de buikwand. Bij deze techniek worden huid en subcutaan weefsel vanuit de laparotomiewond bilateraal gemobiliseerd, waarna de aponeurose van de musculus obliquus externus beiderzijds pararectaal wordt geïncideerd, ongeveer 1 cm lateraal van de musculus rectus abdominis. Aangezien dit een avasculair vlak betreft, kan de ruimte tussen de musculus obliquus externus en internus probleemloos en grotendeels stomp worden gemobiliseerd. Deze dissectie wordt voortgezet tot de achterste axillairlijn. Aanvullend wordt de achterste rectusschede gemobiliseerd van de musculus rectus abdominis voor verdere mediale translatie van de fascieranden. Ramirez[10] verrichtte een kadaverstudie waaruit bleek dat een unilaterale translatie naar mediaal van 5, 10 en 3 cm mogelijk worden op respectievelijk het epigastrisch, umbilicaal en suprapubisch niveau.

10

Centrale vragen waarop dit proefschrift antwoord moest geven waren:

- is het mogelijk om grote buikwanddefecten te sluiten met behulp van de CSM?
- wat is het verklarende mechanisme van deze techniek?
- welke zijn de resultaten van deze techniek op de langere termijn?
- is het zinvol om de buikwand tijdens een CSM te verstevigen met behulp van een mesh?
- kan de CSM veilig worden toegepast in gecontamineerde omstandigheden?
- kunnen we een reproduceerbare methode ontwikkelen om het effect van het sluiten van de buikwand op de mate van doorbloeding van de rectus abdominis spieren te meten?
- wat is de huidige plaats van de CSM tussen alle behandeltechnieken voor grote buikwanddefecten?

Ondanks de tot op heden geringe wetenschappelijk aandacht en het uitblijven van algemene toepassing binnen de heelkunde, heeft de CSM sedert 1990 een positie verworven binnen de hernia chirurgie. Vanwege de potentiële voordelen van deze techniek en de betrekkelijke onbekendheid wordt een overzicht gegeven van alle technische details, alsmede van alle bijkomende peri-operatieve factoren voor buikwandsluiting door middel van de CSM, gebaseerd op onze persoonlijke ervaringen (**Hoofdstuk 2**).

In principe komen alle patiënten met een groot mediaan buikwanddefect (> 5 cm breed en > 50 cm^2) in combinatie met invaliderende symptomen of een locale situatie van de huid die ingrijpen noodzaakt, in aanmerking voor operatieve behandeling met behulp van deze methode. Technische valkuilen bij de operatie zijn een te ruime excisie van de overtollige huid die de breukzak bedekt, een te oppervlakkige subcutane dissectie met bedreigde huid als gevolg, onvoorziene gelijktijdige incisie van de onderliggende musculus obliquus internus, het achterwege laten van mesh augmentatie in geval van onvoldoende spanningsvermindering, insufficiënte mesh underlay ter plaatse van de benige begrenzing van het fasciedefect (processus xiphoideus en os pubis) en bij sluiten van de buik het niet hanteren van de suture length : wound length ratio (totale lengte hechtdraad : lengte wond > 4), zoals die werd beschreven door Israellson.[13]

In **Hoofdstuk 3** worden de mechanische en anatomische veranderingen van de buikwand beschreven die de CSM veroorzaakt, in een humaan kadaver model. Door het aanbrengen van een gestandaardiseerde mediale tractie aan de musculus rectus abdominis, zowel vóór als ná uitvoering van de CSM bij 8 humane kadavers, vonden wij een gemiddelde mediale translatie van 27, 45 en 40 mm op het niveau van respectievelijk xiphoid, navel en Spina Iliaca Anterior Superior (SIAS), waardoor defecten van 5.4, 9.0 en 8.0 cm breed gesloten zouden kunnen worden. Incisie en mobilisatie van de obliquus externus musculatuur leverde beduidend méér winst op dan incisie van de achterste rectusschede. Onze hypothese van caudo-mediale rotatie rondom de origo van de obliquus internus en transversus, kon niet worden bevestigd, aangezien dit slechts in één kadaver werd gevonden. Ondanks dat het achterliggende mechanisme niet kon worden verklaard, werd hierdoor de beperkte rol van mobilisatie van de achterste rectus schede tijdens de CSM aangetoond.

In **Hoofdstuk 4** worden de lange termijn resultaten beschreven van reconstructie van grote buikwanddefecten door middel van de CSM met speciale aandacht voor recidieven, activiteiten in het dagelijkse leven (ADL) en de invloed van toevoeging van een mesh ter versteviging (mesh augmentatie). Gedurende 6 jaar werden 95 patiënten met grote buikwanddefecten behandeld. Wond gerelateerde complicaties kwamen frequent voor waaronder oppervlakkige wondinfecties in 24 gevallen. Na een mediane follow-up duur van 4 jaar (1 – 95 maanden), werd bij 15 patiënten (15.7 %) een recidief aangetroffen bij lichamelijk onderzoek, waarvan 13 patiënten asymptomatisch en volledig tevreden met hun situatie waren. In de groep van 26 patiënten met mesh augmentatie werd één klein asymptomatisch recidief gevonden (3.8 %) juist onder de processus xiphoideus. De overige 14 recidieven werden gevonden in de groep van 69 patiënten zónder mesh augmentatie (20 %). Gebruik makend van de Fisher's exact test blijkt er een statistisch significant verschil te bestaan tussen patiënten behandeld mét en zónder mesh augmentatie, voor wat betreft het recidiefpercentage na 4 jaar ($p = 0.036$).
De meeste patiënten waren in staat om alle activiteiten in het dagelijkse leven uit te voeren zonder beperkingen. Tweeëntwintig patiënten voelden zich beperkt voor wat betreft zwaar tilwerk en 12 patiënten hadden problemen met buigen om hun veters te strikken. Deze klachten konden niet gerelateerd worden aan het gebruik van mesh

augmentatie. De resultaten steunen onze overtuiging dat mesh augmentatie van de CSM op lange termijn betere resultaten geeft.

De chirurgische behandeling van grote en tevens gecontamineerde buikwanddefecten blijft een groot probleem. Vanwege het infectierisico worden dergelijke patiënten meestal in etappes behandeld (multi-stage repair).[14-18] Omdat regelmatig een mesh wordt gebruikt voor reconstructie van buikwanddefecten en toepassing van kunststof in een gecontamineerd operatiegebied frequent tot diepe wondinfecties leidt, wordt in geval van contaminatie vaak een toevlucht gezocht in een stapsgewijze aanpak. Die bestaat uit een initiële tijdelijke bedekking met mesh gevolgd door het aanbrengen van een gedeeld huidtransplantaat (split skin) met tot slot mesh excisie en definitieve sluiting van de buik. Helaas is deze strategie niet alleen tijdsintensief, maar gaat die vaak ook gepaard met veel morbiditeit waardoor in veel gevallen het laatste stadium (sluiting van de buik) niet eens meer wordt bereikt.[14,16] Direct herstel van het buikwanddefect ondanks contaminatie (one stage repair) is niet alleen een aantrekkelijk alternatief, maar is soms de enige beschikbare optie. Om de toepasbaarheid van de CSM in geval van contaminatie te evalueren hebben we in **Hoofdstuk 5** onze ervaringen bij 26 patiënten beschreven bij wie ten tijde van buikwandreconstructie contaminatie bestond. Bij 4 patiënten was ondanks contaminatie toch een mesh augmentatie uitgevoerd omdat de spanningsvermindering door de CSM als onvoldoende werd beoordeeld. Tweederde (16 patiënten) van deze populatie liep postoperatief één of meerdere complicaties op waarbij een oppervlakkige wondinfectie het meest frequent voorkwam (n=5). Tot onze verassing bleek bij geen enkele van de 4 patiënten met mesh augmentatie een wond gerelateerde complicatie te zijn opgetreden. Na een mediane follow-up duur van 27 maanden vonden we bij 2 patiënten een klein asymptomatisch recidief wat geen herstel behoefde. Deze beide patiënten hadden géén mesh augmentatie gekregen. Onze resultaten wijzen erop dat ook gecontamineerde grote buikwanddefecten succesvol door middel van een zogenaamde one-stage procedure met de CSM gesloten kunnen worden maar dat de kans op postoperatieve morbiditeit aanzienlijk is. Gebaseerd op onze ervaring bij slechts een klein aantal patiënten, lijkt het erop dat de aanwezigheid van contaminatie het gebruik van een synthetische mesh niet uitsluit.

Eén van de voornaamste functies van de buikwand is het opvangen en weerstand bieden aan de krachten van het diafragma gedurende geforceerde uitademing. In geval van patiënten met een groot buikwanddefect is deze functie verminderd of geheel afwezig zodat een zogenaamde 'buikademhaling' vaak onmogelijk is. Verondersteld wordt dat ook de longfunctie belemmerd wordt, hoewel specifiek onderzoek hieromtrent ontbreekt. Bij reconstructie van een groot buikwanddefect zal door repositie van hetgeen zich in de breukzak bevindt, de intra abdominale inhoud toenemen. Als gevolg hiervan zal een elevatie van het diafragma optreden wat het intra thoracale volume vermindert en de pulmonale compliantie beperkt. Een toename van de intra abdominale volume capaciteit is derhalve een voorwaarde om repositie van breukzakinhoud en buikwandsluiting te kunnen realiseren, zónder de pulmonale functie te beperken. Sluiting van grote buikwanddefecten door middel van de CSM kan theoretisch voor een verbetering van de longfunctie zorgen omdat functioneel continuïteitsherstel van de buikwand een buikademhaling weer mogelijk maakt en het intra abdominaal volume vergroot waardoor repositie van breukzakinhoud mogelijk is, zónder het intra thoracale volume te verminderen.

Veel patiënten met een langer bestaand groot buikwanddefect ondervinden rugklachten. Herstel van het buikwanddefect kan een positieve invloed hebben op deze klachten en daardoor ook op de kwaliteit van leven.[19] In **Hoofdstuk 6** beschrijven we de resultaten van een prospectief onderzoek naar de effecten van de CSM op de kwaliteit van leven, longfunctie en buikspierfunctie in een pilotstudy bij 6 patiënten. Allen waren ouder dan 18 jaar, hadden een groot mediaan buikwanddefect op navelhoogte, géén aanwijzingen voor astma bronchiale of emfyseem (GOLD stadium IIb of hoger), géén enterocutane fisteling, stoma of andere rectusmusculatuur beschadigende procedures of aandoeningen op dat moment (of in het verleden) en ze ondergingen géén spoedoperatie of gelijktijdig herstel van de continuïteit van het maagdarmstelsel. Door vergelijking van de preoperatief bepaalde kwaliteit van leven (Short Form 36), longfunctie (spirometrie) en buikspierfunctie (sit-ups en benen gestrekt heffen) met de situatie 6 maanden postoperatief konden we vaststellen dat de CSM géén beperking veroorzaakt van de longfunctie, de kwaliteit van leven subjectief verbetert en objectief de buikspierfunctie en mogelijkheid tot lichamelijke inspanning verbetert.

Wondgerelateerde complicaties en fasciedehiscentie komen nogal eens voor bij patiënten met een verhoogde Intra Abdominale Druk (IAP) na een laparotomie. Te strak aangetrokken hechtingen zullen neutrofiele granulocyten aantrekken rondom de hechtdraden waardoor collagenolysis en ischaemische necrose op zal treden en fasciedehiscentie kan ontstaan.[20-22] Wondgenezing in het algemeen is grotendeels afhankelijk van adequate weefselperfusie. De mate van collageenvorming en de trekkracht van een wond kunnen negatief beïnvloed worden door een verminderde weefsel perfusie met lagere zuurstofspanning.[23] Langdurig verlaagde perfusie van het musculaire deel van de buikwand zou daarom een voorname rol kunnen spelen bij de ontwikkeling van een verzwakt litteken en het ontstaan van een littekenbreuk kunnen bevorderen.

Wij onderzochten de relatie tussen de weefselperfusie in de rectus abdominis musculatuur en een gestandaardiseerde geleidelijke toename van de IAP en hebben dit beschreven in **Hoofdstuk 7**. Feitelijk is dit de eerste studie die deze relatie bij de mens beschrijft. Wij vonden een significant verminderde rectusperfusie wanneer de IAP toenam tot 20 mmHg. Een intra musculair geplaatste Lycox-zuurstof electrode lijkt een bruikbare methode om peroperatief op eenvoudige wijze veranderingen in de weefselperfusie van de buikspieren, ten gevolge van een verhoogde IAP, bij hemodynamisch stabiele patiënten te meten. Omdat het systemische zuurstofgehalte onaangetast bleef, de zuurstoftransportcapaciteit niet afnam en klinisch relevante acidose niet optrad, kunnen eventuele secundaire cardio-respiratoire effecten ten gevolge van een verhoogde IAP niet verantwoordelijk zijn voor de specifiek verminderde perfusie van de rectus musculatuur. Deze lijkt dus uitsluitend veroorzaakt te worden door de verhoogde IAP.

Meerdere auteurs hebben geprobeerd om een algemeen toepasbaar classificatiesysteem voor patiënten met littekenbreuken te ontwikkelen. Vreemd genoeg bestaat er op dit moment nog altijd géén consensus over de definitie van verschillende typen buikwandherniaties. Evenmin bestaan er criteria voor de manier waarop een groot buikwanddefect gereconstrueerd zou moeten worden. In **Hoofdstuk 8** beschrijven wij de resultaten van een review gebaseerd op de huidige literatuur over alle verschillende methoden van buikwandreconstructie, alsmede op basis van onze eigen ervaringen. We concludeerden dat tot op heden géén onderzoek is gedaan naar het fundamentele dilemma of grote buikwanddefecten bij voorkeur overbrugd moeten worden (bridging) of dat de circumferentiële musculaire continuïteit van de buikwand hersteld moet worden (closing). Van alle beschreven methoden wordt het preoperatieve progressieve pneumoperitoneum niet vaak gebruikt, maar dit blijft voor sommige indicaties een bruikbare aanvulling op de huidige technieken. Weefsel expansie (het geleidelijk oprekken van weefsel door middel van een vulbaar reservoir) is tijdrovend, vereist op maat gemaakte (dure) zogenaamde tissue expanders en het oprekken van het weefsel gebeurt niet altijd in de gewenste richting, waardoor toepassing van weefsel expansie vaak een beperkte meerwaarde heeft.

Onze resultaten met de CSM gecombineerd met mesh augmentatie zijn hoopgevend, in het licht van andere (geaugmenteerde) chirurgische technieken. Het aanvullend gebruiken van een synthetische mesh voor augmentatie bij een CSM lijkt zinvol, aangezien dit minder recidieven lijkt te geven zónder daarbij beperkingen in het dagelijkse leven te veroorzaken. Tot op heden is géén van de mogelijke technieken voor sluiting van grote buikwanddefecten in een degelijke prospectief gerandomiseerde gecontroleerde trial (RCT) met langdurige follow-up onderzocht. Gezien de grote variatie in voorgeschiedenis en actuele pathologie van individuele patiënten en alle mogelijke behandelstrategieën, is het waarschijnlijk een illusie om aan te nemen dat zo’n grote RCT in de toekomst uitgevoerd zal worden om de superioriteit van één van de technieken aan te tonen.

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Curriculum Vitae

Curriculum Vitae

De auteur van dit proefschrift werd op 8 november 1967 geboren te Schijndel, alwaar hij zijn jeugd heeft doorgebracht. Op 30 mei 1986 behaalde hij het VWO diploma aan het Mgr. Zwijsen College te Veghel. Een dag later startte hij de opleiding tot jachtvlieger bij de Koninklijke Luchtmacht aan de Rijksluchtvaartschool te Eelde. Datzelfde jaar werd hij alsnog nageplaatst voor de Katholieke Universiteit van Nijmegen en begon hij aan zijn studie Geneeskunde. Naast zijn studie deed hij wetenschappelijk onderzoek binnen de afdeling Kindernefrologie (M.C.W.J. de Jong) van het UMC St. Radboud naar de effecten van recombinant groeihormoon bij kinderen met een terminale nierinsufficiëntie. In 1992 behaalde hij zijn doctoraalexamen. Tijdens zijn co-schappen werd hij in het toenmalige Groot Ziekengasthuis te 's-Hertogenbosch enthousiast voor de Algemene Chirurgie en verrichtte hij wetenschappelijk onderzoek in samenwerking met het UMC St. Radboud (Dr. W.A.H. Gelderman, Prof. dr. Th. Wobbes, Prof. dr. R.P. Veth) op het gebied van de behandeling van pathologische fracturen.

Op 17 juni 1994 trouwde hij met Sandra van Rosmalen. Nadat hij in september 1994 het artsexamen behaalde, startte hij als AGNIO chirurgie binnen het UMC St. Radboud en verrichtte in die periode onderzoek naar de Sepsis-related Organ Failure Assessment score (SOFA) in samenwerking met de afdeling Intensive Care (Prof. dr. R.J.A. Goris, Prof. dr. J.L. Vincent). In 1995 werd hij aangenomen voor de opleiding tot chirurg in de regio Utrecht waarmee hij 1 januari 1996 kon starten. De tussenliggende 4 maanden werkte hij als AGNIO op de afdeling Intensive Care van het UMC St. Radboud (Drs. S.J. van Leeuwen). Gedurende de eerste helft van zijn opleiding in het toenmalige AZU (UMCU) startte hij met onderzoek naar het verklarende mechanisme achter de Componenten Separatie Methode (CSM) en de resultaten van behandeling bij patiënten met grote littekenbreuken, de basis voor dit proefschrift (opleider Prof. dr. Th.J.M.V. van Vroonhoven). Vanaf 1999 volgde hij de laatste drie jaar van zijn opleiding in het Jeroen Bosch Ziekenhuis (GZG) alwaar hij de CSM met medewerking van Drs. J. Olsman steeds vaker toepaste en zich verder bekwaamde in de traumatologie (opleider Dr. J. Wever). In 2002 werd hij chirurg en bleef werkzaam in het Jeroen Bosch Ziekenhuis op de afdeling chirurgie, alwaar hij startte met de CHIVO opleiding longchirurgie. In deze periode werd het onderzoek naar de CSM voortgezet en daarnaast participeerde hij in onderzoek naar het effect van co-morbiditeit op de behandeling en prognose van oudere patiënten met NSCLC in samenwerking met het IKZ Eindhoven (Dr. M.L.G. Janssen-Heijnen en Prof. dr. J.W.W. Coebergh). Na voltooiing van de CHIVO opleiding trad hij toe tot de maatschap chirurgie van het Jeroen Bosch Ziekenhuis (GZG) waar hij momenteel werkzaam is.

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