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REVIEW

European Hernia Society guidelines on the closure of abdominal wall incisions

F. E. Muysoms · S. A. Antoniou · K. Bury · G. Campanelli · J. Conze · D. Cuccurullo · A. C. de Beaux · E. B. Deerenberg · B. East · R. H. Fortelny · J.-F. Gillion · N. A. Henriksen · L. Israelsson · A. Jairam · A. Jänes · J. Jeekel · M. López-Cano · M. Miserez · S. Morales-Conde · D. L. Sanders · M. P. Simons · M. Śmietański · L. Venclauskas · F. Berrevoet

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Abstract
Background The material and the surgical technique used to close an abdominal wall incision are important determinants of the risk of developing an incisional hernia. Optimising closure of abdominal wall incisions holds a potential to prevent patients suffering from incisional hernias and for important costs savings in health care.
Methods The European Hernia Society formed a Guidelines Development Group to provide guidelines for all surgical specialists who perform abdominal incisions in adult patients on the materials and methods used to close the abdominal wall. The guidelines were developed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach and methodological guidance was taken from Scottish Intercollegiate Guidelines Network (SIGN). The literature search included publications up to April 2014. The guidelines were written using the AGREE II instrument. An update of these guidelines is planned for 2017.
Results For many of the Key Questions that were studied no high quality data was detected. Therefore, some strong recommendations could be made but, for many Key Questions only weak recommendations or no recommendation could be made due to lack of sufficient evidence.
Recommendations To decrease the incidence of incisional hernias it is strongly recommended to utilise a non-midline approach to a laparotomy whenever possible. For elective midline incisions, it is strongly recommended to perform a continuous suturing technique and to avoid the use of rapidly absorbable sutures. It is suggested using a slowly absorbable monofilament suture in a single layer aponeurotic closure technique without separate closure of the peritoneum. A small bites technique with a suture to wound length (SL/WL) ratio at least 4/1 is the current recommended

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F. E. Muysoms (✉)
Department of Surgery, AZ Maria Middelares, Kortrijksesteenweg 1026, 9000 Ghent, Belgium
e-mail: filip.muysoms@azmmsj.be

S. A. Antoniou
Center for Minimally Invasive Surgery, Neuwerk Hospital, Mönchengladbach, Germany

S. A. Antoniou
Department of General Surgery, University Hospital of Heraklion, University of Crete, Heraklion, Greece

K. Bury
Department of Cardiac and Vascular Surgery, Medical University of Gdansk, Gdańsk, Poland

G. Campanelli
General and Day Surgery, Center of Research and High Specialization for Abdominal Wall Pathology and Hernia Repair, Istituto Clinico Sant' Ambrogio, University of Insubria, Milan, Italy

J. Conze
UM Hernia Centre, Munich, Germany

J. Conze
Department of General, Visceral and Transplantation Surgery, University Hospital of the RWTH Aachen, Aachen, Germany

D. Cuccurullo
Department of General and Laparoscopic Surgery, Monaldi Hospital, Azienda Ospedaliera dei Colli, Naples, Italy

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method of fascial closure. Currently, no recommendations can be given on the optimal technique to close emergency laparotomy incisions. Prophylactic mesh augmentation appears effective and safe and can be suggested in high-risk patients, like aortic aneurysm surgery and obese patients. For laparoscopic surgery, it is suggested using the smallest trocar size adequate for the procedure and closure of the fascial defect if trocars larger or equal to 10 mm are used. For single incision laparoscopic surgery, we suggest meticulous closure of the fascial incision to avoid an increased risk of incisional hernias.

Keywords Guidelines · Abdominal wall closure · Laparotomy · Laparoscopy · Prophylactic mesh · Prevention · Incisional hernia

Introduction

Background

Incisional hernias are a frequent complication of abdominal wall incisions, but a wide range of incisional hernia rates are reported [1–6]. The weighted mean incisional hernia rate at 23.8 months was 12.8 % in a systematic review and meta-regression study [7], but incidence rates up to 69 % have been reported in high-risk patients with prospective long-term follow-up [8]. The reported incidence is determined by several factors: the patient population studied, the type of abdominal wall incision, the length of follow-up and the method of incisional hernia diagnosis. Risk factors for incisional hernias include postoperative surgical site infection, obesity and abdominal aortic aneurysm [9–11]. Nevertheless, it seems that the suture material and the surgical technique used to close an abdominal wall incision, are the most important determinants of the risk of developing an incisional hernia [1, 12]. The development of an incisional hernia has an important impact on the patients' quality of life and body image [13]. Furthermore, the repair of incisional hernias still has a high failure rate with long term recurrence rates above 30 %, even when mesh repair is performed [14–16]. Optimising the surgical technique to close abdominal wall incisions using evidence based principles, holds a potential to prevent patients suffering from incisional hernias and the potential sequelae of incisional hernia repairs [17]. The mean direct and indirect costs for the repair of an average incisional hernia in an average patient in France in 2011 was € 7,089 [18]. Thus, reducing the incisional hernia rate by optimising the closure of abdominal wall incisions holds a great potential for costs savings in the use of health care facilities and in reducing postoperative disability.

The European Hernia Society (EHS) originated from the "Groupe de la recherche de la paroi abdominal" (GREPA), which was founded in 1979 with the aim: "The promotion of abdominal wall surgery, the study of anatomic, physiologic and therapeutic problems related to the pathology of the abdominal wall, the creation of associated groups which will promote research and teaching in this field, and the

A. C. de Beaux
Department of General Surgery, The Royal Infirmary of Edinburgh, Edinburgh, UK

E. B. Deerenberg · A. Jairam
Department of Surgery, Erasmus MC University Medical Center Rotterdam, Rotterdam, The Netherlands

B. East
Department of Surgery, Second Faculty of Medicine, Charles University in Prague, Prague, Czech Republic

R. H. Fortelny
Department of General, Visceral and Oncological Surgery, Hernia Center, Wilhelminenspital, Vienna, Austria

J.-F. Gillion
Unité de Chirurgie Viscérale et Digestive, Hôpital Privé d'Antony, Antony, France

N. A. Henriksen
Bispebjerg Hospital and Department of Gastroenterology, Digestive Disease Center, Hvidovre Hospital, Copenhagen, Denmark

L. Israelsson
Department of Surgery and Perioperative Science, Umeå University, Umeå, Sweden

A. Jänes
Upper GI and Trauma Surgery, Department of Surgery, Sundsvall Hospital, Sundsvall, Sweden

J. Jeekel
Department of Neurosciences, Erasmus MC University Medical Center Rotterdam, Rotterdam, The Netherlands

M. López-Cano
Abdominal Wall Surgery Unit, Hospital Universitario Vall d'Hebrón, Universidad Autónoma de Barcelona, Barcelona, Spain

M. Miserez
Department of Abdominal Surgery, University Hospitals, KU Leuven, Leuven, Belgium

S. Morales-Conde
Unit of Innovation in Minimally Invasive Surgery, University Hospital Virgen del Rocío, Seville, Spain

D. L. Sanders
Department of Surgery, Derriford Hospital, Plymouth, UK

M. P. Simons
Department of Surgery, Onze Lieve Vrouw Gasthuis, Amsterdam, The Netherlands

development of interdisciplinary relations". During the autumn board meeting of the EHS in September 2013 in Italy it was decided to extend our mission to actively promote the prevention of incisional hernias by the Sperlonga statement: "Maybe we should first learn and teach how to prevent incisional hernias, rather than how to treat them?"

Objective

The objective is to provide guidelines for all surgical specialists who perform abdominal incisions in adult patients on the optimal materials and methods used to close the abdominal wall. The goal is to decrease the occurrence of both burst abdomen and incisional hernia. The guidelines refer to patients undergoing any kind of abdominal wall incision, including visceral surgery, gynaecological surgery, aortic vascular surgery, urological surgery or orthopaedic surgery. Both open and laparoscopic surgeries are included in these guidelines.

Methods

As EHS secretary of Quality, Filip Muysoms, under the auspices of the European Hernia Society board, proposed the Guidelines Development Group. The project was presented to the EHS board and accepted during the board meeting in Sperlonga, Italy, on September 28th 2013. The members of the Guidelines Development Group were chosen to recruit key opinion leaders and researchers on the subject from Europe. A geographical distribution across European countries was attempted and some younger surgeons having performed research on the subject were included in the Guidelines Development Group. Many of the members have contributed previously in producing guidelines on a national and international level. The Guidelines Development Group included abdominal wall surgeons, upper gastro-intestinal surgeons, hepato-biliary surgeons, colorectal surgeons and a vascular surgeon.

During a Kick Off meeting of the Guidelines Development Group in the Bonham Hotel in Edinburgh on October 28th 2013, the members attended a seminar on the methodological aspect of developing guidelines by Robin T Harbour, the Lead Methodologist of the Scottish Intercollegiate Guidelines Network (SIGN) [19]. The AGREE II instrument was used from the start of the project to guide our methodology and structure of producing the guidelines [20]. AGREE II gives as definition for the Quality of a guideline: "The confidence that the potential biases of guideline development have been addressed adequately and that the recommendations are both internally and externally valid, and are feasible for practice." During this first meeting Key Questions were formulated and translated into 24 patients-intervention-comparison-outcome (PICO) formats. For each Key Question at least three Guidelines Development Group members were assigned as investigators and specific search terms were formulated. The Key Questions with their PICO's and assigned authors are listed in addendum 1.

On November 11th 2013, a meeting in Glasgow at the SIGN headquarters was held with the steering committee of the Guidelines Development Group to discuss the search strategy. A clinical librarian working for SIGN performed the primary literature research for all Key Questions. This involved a search for systematic reviews and/or meta-analyses on the Key Questions in Medline, Embase, NIHR CRD, NICE and The Cochrane library. The PRISMA flow diagram is shown in Fig. 1 and the search terms used are in addendum 2. The Guidelines Development Group members evaluated the systematic reviews for their relevance to the Key Questions and a qualitative assessment was done using the SIGN checklist No 1 for systematic reviews and meta-analyses [19]. Only systematic reviews of High Quality were used as basis for the guidelines development. A second search (no filters) on the Key Questions was performed for relevant RCT's published after the end of the search performed for the systematic reviews involved. If no High Quality systematic review was identified for a Key Question, the working group members performed a separate systematic review using the PRISMA statement methodology [21]. To avoid lengthening of this guidelines manuscript, the results of these systematic reviews will be submitted as a separate manuscript on behalf of "The Bonham Group", which are the members of the Guidelines Development Group. The members working together on a Key Question provided a Summary of Findings table from the results of the literature search, which were presented and discussed during the second group meeting.

The second Guidelines Development Group meeting was held in Edinburgh on April 25th 2014. For evaluation of evidence, the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach was used [22]. For each Key Question, a level of evidence was proposed using the GRADE approach and four levels of quality of the body of evidence were used: high, moderate, low, very low (Table 1). Based on the research evidence,

M. Śmietański
Department of General and Vascular Surgery, Ceynowa Hospital in Wejherowo, Wejherowo, Poland

L. Venclauskas
Department of Surgery, Lithuanian University of Health Sciences, Kaunas, Lithuania

F. Berrevoet
Department of General and Hepatobiliary Surgery and Liver Transplantation Service, University Hospital Ghent, Ghent, Belgium

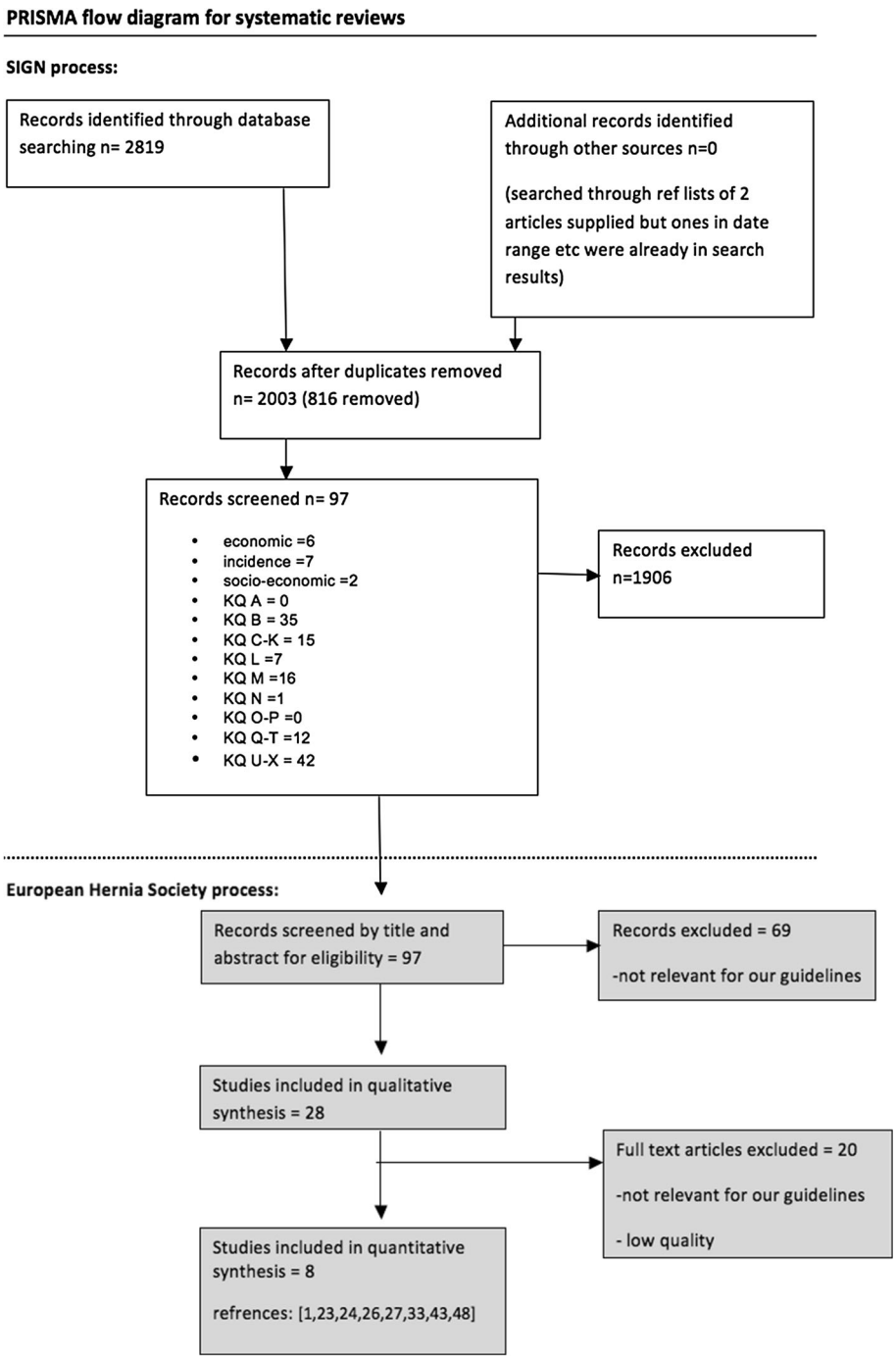

Fig. 1 PRISMA flow diagram for the search for systematic reviews and/or meta-analyses performed by Scottish Intercollegiate Guidelines Network (SIGN) for the Guidelines Development Group of the European Hernia Society guidelines on the closure of abdominal wall incisions. The search was performed in November 2013 and included searches in Medline, Embase, NIHR CRD, NICE and The Cochrane library

the clinical experience and patient values the Guidelines Development Group formulated a recommendation for each Key Question. In the GRADE approach only three levels of recommendation are used: strong recommendation, weak recommendation and no recommendation.

The results of the guidelines proposed by the Guidelines Development Group were presented during the 36th Annual International Congress of the European Hernia Society in Edinburgh on May 31st 2014. The manuscript was subsequently written by the first author in a uniform manner for all Key Questions and send for review and agreement by all co-authors. Prior to submission, the manuscript of the guidelines was externally reviewed by experts and evaluated using the AGREE II instrument.

Results

The results of the searches are shown in the PRISMA flow diagram in Fig. 1. From the 97 records detected by the

Table 1 Using the GRADE approach to guideline development [22] the Quality of the body of evidence is rated (high/moderate/low/very low) and the recommendations are graded as strong or weak

Grading the Quality of the body of evidence for each Key Questions using the GRADE approach			
Underlying methodology	Quality rating	Symbols	Definitions
Randomized trials; or double-upgraded observational studies	High	⊠⊠⊠⊠	Further research is very unlikely to change our confidence in the estimate of effect
Downgraded randomized trials; or upgraded observational studies	Moderate	⊠⊠⊠□	Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate
Double-downgraded randomized trials; or observational studies	Low	⊠⊠□□	Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate
Triple-downgraded randomized trials; or downgraded observational studies; or case series/case reports	Very low	⊠□□□	Any estimate of effect is very uncertain
Grading of recommendations using the GRADE approach			
Strong recommendation	Based on the available evidence, if clinicians are very certain that benefits do, or do not, outweigh risks and burdens they will make a strong recommendation		
Weak recommendation	Based on the available evidence, if clinicians believe that benefits and risks and burdens are finely balanced, or appreciable uncertainty exists about the magnitude of benefits and risks, they must offer a weak recommendation		
No recommendation	If based on the literature research no evidence could be found, no recommendation can be made		

SIGN process, 69 records were excluded based on the title and abstract as not being relevant to the guidelines. The remaining 28 systematic reviews [1, 23–49] were assessed by full text for their relevance to the Key Questions and if retained were assessed qualitatively using the SIGN checklist No 1 [19]. Additional searches on PubMed and by checking the references of all manuscripts were performed by the members of the Guidelines Development Group assigned to each Key Question. Relevant studies published up until April 2014 were included to provide the Summary of Evidence tables.

Which diagnostic modality is the most suitable to detect incisional hernias?

No systematic reviews on diagnostic modalities for incisional hernias were found. The PRISMA flow diagram is shown in addendum 3 (Key Question A). Fifteen records were included in the qualitative analysis [3–6, 50–60]. Only four studies were retained as High Quality and are listed in the Summary of Findings table (Table 2) [5, 50–52].

The quality of most studies investigating the diagnostic accuracy of imaging techniques was low to very low. Only some provided a sensitivity analysis. Because no studies compared different diagnostic modalities in a similar methodology and with similar study arms, no pooling of data was useful or possible. In general, most studies show that medical imaging will increase the rate of detection of incisional hernias compared to physical examination. In an everyday clinical setting this is usually not important, because most asymptomatic hernias do not require treatment and their diagnosis is thus not necessary.

CT scan is reliable and reproducible, whereas ultrasound is more operator-dependant. However, CT scan will induce a radiation load to the patients and ultrasound is more accessible in most health care settings. A good standardisation and dynamic evaluation by ultrasound of the abdominal wall is needed, as described by Beck et al. [51] as the dynamic abdominal sonography for hernia (DASH) technique.

The difference in accuracy between physical examination and imaging technique is most important in the context of comparative studies evaluating incisional hernia rate. Next to the method of incisional hernia diagnosis the length of follow-up is important. Fink et al. [2] reported in a follow-up study of two prospective trials an increase from 12.6 % at 12 months to 22.4 % at 36 months ($p < 0.001$) and concluded that follow-up for 3 years should be mandatory in any study evaluating the rate of postoperative incisional hernia after midline laparotomy.

Statement	It is recommended that prospective studies with incisional hernias as a primary outcome integrate medical imaging, either dynamic ultrasound or CT scan, in the follow-up.	☒☒☐☐	strong
Statement	It is recommended that studies with incisional hernias as a primary outcome include follow-up of at least 24 months (and preferably 36 months).	☒☒☐☐	strong

Does the type of abdominal wall incision influence the incidence of incisional hernias or burst abdomen?

Laparotomy incisions can be classified as midline, transverse, oblique or paramedian incisions [61]. The PRISMA flow diagram is shown in addendum 3 (Key Question B). Six systematic reviews have compared midline laparotomies to alternative incisions [26, 27, 31, 36, 38, 61], but only two were considered High Quality [26, 27]. A recent systematic review by Bickenback et al. [26] compared midline, transverse (including oblique) and paramedian incisions. This review included all relevant studies from previous reviews and no additional RCT's were detected that were published after this review. The literature search of this systematic review [26] identified studies published until 2009 and 24 RCT's directly comparing different laparotomy incisions were included in the analysis. The incisional hernia rates after non-midline incisions were significantly lower compared to the incisional hernia rates after midline incisions, for both transverse incisions (RR = 1.77; 95 % CI:1.09–2.87) and paramedian incisions (RR = 3.41; 95 % CI: 1.02–11.45) [26]. However, data on burst abdomen (deep wound dehiscence or fascial dehiscence) were not significantly different between the different incisions types.

A Cochrane review by Brown et al. [27] published in 2005 and updated in 2011, compared transverse versus midline incisions, but excluded studies comparing paramedian incisions. A decreased incisional hernia rate after transverse incisions was reported compared to midline incisions (OR = 0.49; 95 % CI: 0.30–0.79).

Both reviews concluded that non-midline incisions significantly reduced the risk of incisional hernia compared to midline incisions, but did not influence the risk of burst abdomen. Interestingly, the Cochrane conclusions were more moderate, due to methodological and clinical heterogeneity of the studies and the risk of potential bias.

What is the optimal technique to close a laparotomy incision?

Ten systematic reviews on the techniques and/or the materials to close abdominal wall incisions were identified [1, 32, 34, 37, 38, 42, 43, 48, 62, 63]. The PRISMA flow diagram is shown in addendum 3 (Key Question C–G). The data from the different systematic reviews are very incoherent and conclusions are often completely contradictory. The overall quality of most systematic reviews is low and therefore, several should be rejected as evidence to create guidelines. A major problem to identify the evidence from the literature is the fact that most prospective studies compared several variables between the study arms. Moreover, the populations studied are often very different: midline only or including other incisions, emergency or elective surgery, and different operative indications.

The current guidelines on techniques and materials are based on the systematic reviews by Diener et al. [1] and van't Riet et al. [48] which were evaluated as High Quality. Both systematic reviews included only studies involving midline laparotomies and the review by Diener et al. was the only one to distinguish between elective or emergency surgery. The systematic review by Sajid et al. [43] was used for the question on suture materials and a recent Cochrane review by Gurusamy et al. [63] was used for the question on peritoneal closure.

Using separate PICO's the shortcoming of many study designs to deliver clear answers becomes obvious. Another shortcoming in most studies on closure of laparotomies is the failure to monitor the technical details of the suturing technique, like the SL/WL ratio and the stitch size. As demonstrated by Israelsson [64] this might be an important confounding factor in studies comparing different suture materials. An updated systematic review taking into account the mentioned shortcomings of individual studies might be performed, but for these guidelines the conclusions are based on the data from the currently available

Statement	Non-midline incisions are recommended where possible.	☒☒☒☐	strong

Table 2 Summary of Findings table for Key Question A: which diagnostic modality is the most suitable to detect incisional hernias?

Bibliographic citation [reference]	Study type	SIGN assessment	Number of patients	Patient characteristics	Intervention	Comparison	Length of follow-up	Outcome measure
Baucom et al. Journal of the American College of Surgeons 2013; 218(3):363–6 [50]	Prospective cohort study	High Quality++	181	Patients seen at a general surgery department who had a prior abdominal operation and an available CT scan within six months before the visit	Physical examination by a surgeon	CT scan reviewed by surgeon	Not available	Physical examination had a low sensitivity (77 %) and negative predictive value (77 %). It fails to detect 23 % of hernias and in 32 % of the patients with a BMI $\geq$ 30 kg/m^2
General comments: adequate designed study to compare physical examination to CT scan diagnosis of incisional hernias. CT scan was used as "gold standard" for the sensitivity analysis								
Beck et al. Journal of the American College of Surgeons 2013;216(3):447–53 [51]	Prospective cohort study	High Quality++	181	Patients seen at a general surgery department who had a prior abdominal operation and an available CT scan within six months before the visit	Dynamic abdominal ultrasound by surgeon	CT scan reviewed by surgeon	Not available	Dynamic Ultrasound has a high sensitivity (98 %) and specificity (88 %). It has a positive predictive value of 91 % and negative predictive value of 97 %. It is a good alternative to CT scan diagnosis
General comments: paper from the same group as Baucom et al. Concerns the same patient population. Adequate designed study to compare dynamic ultrasound to CT scan diagnosis of incisional hernias. CT scan was used as "gold standard" for the sensitivity analysis								
den Hartog et al. Hernia 2009;13(1):45–8 [5]	Prospective cohort study	High Quality++	40	Patients that had aortic surgery by midline incision at least 12 months before	Ultrasound by radiologist	CT scan (by 2 independent radiologists	Mean 3.4 years	Incisional hernia prevalence was 60.0 % with CT scan and 42.5 % with ultrasound. The sensitivity of US was 70.8 % and the specificity 100 %. Us has a positive predictive value of 100 % and a negative predictive value of 69.6 %. CT scan diagnosis of the incisional hernias has a good intra- and inter -observer reliability
General comments: adequate designed study to compare ultrasound to CT scan diagnosis of incisional hernias. No comparison to physical examination. Limited number of patients. CT scan was used as "gold standard" for the sensitivity analysis								
Schreinemacher et al. Arch Surg. 2011;146:94–9 [52]	Retrospective cohort study with prospective examination	High Quality++	111	Patients that have a closure of a temporary stoma (42 % ileostomies and 58 % colostomies)	Ultrasound of the abdominal wall by surgeon	Physical examination by surgeon	Median 35 months	Incisional hernia prevalence was 32.4 % with ultrasound evaluation. Physical examination had a sensitivity of 58.3 % and a specificity of 97.3 %. The positive predictive value was 91.3 % and the negative predictive value was 83 %
General comments: both examinations were performed by the same person. Ultrasound was used a "gold standard" for the sensitivity analysis								

Statement	It is recommended that prospective randomized studies on the suture material to close abdominal wall incisions use the same suturing technique in both study groups.	strong
Statement	It is recommended that prospective randomized studies assessing the technique to close abdominal wall incisions use the same suture material in both study groups.	strong

systematic reviews. The protocol for an ongoing Cochrane review [65] was published in 2006 but the final data have not yet been published.

Continuous suturing versus interrupted sutures

Both meta-analyses concluded that continuous suturing for closure of midline laparotomies was beneficial compared to interrupted closure [1, 48]. Diener et al. [1] found a significant lower incisional hernia rate for continuous suturing (OR 0.59: $p = 0.001$) in elective surgery. Most of the included studies were at high risk of bias because the interrupted study arm used rapidly absorbable multifilament sutures and the continuous arm used either non-absorbable or slowly absorbable monofilament sutures. van't Riet et al. [48] included studies involving emergency laparotomies and did not find any difference in incisional hernia rate between interrupted and continuous suturing. Continuous suturing was recommended because it was significantly faster.

Closure versus non-closure of the peritoneum

The Cochrane review by Gurusamy et al. [63] concluded that there was no short-term or long-term benefit in peritoneal closure. Five studies were included but were heterogeneous in type of incision (midline and non-midline) and included both elective and emergency laparotomies. In all studies, the peritoneum was closed as a separate layer in the study arm with peritoneal closure.

Mass closure versus single layer closure

The search for the most appropriate layers to be sutured when closing a laparotomy is hampered by the lack of good definitions on what constitutes a mass closure, layered closure or single layer closure. No clinical studies directly comparing different closure methods were found.

For future research the Guidelines Development Group proposes the following definitions:

- Mass closure: the incision is closed with a suture bite including all layers of the abdominal wall except the skin.
- Layered closure: the incision is closed with more than one separate layer of fascial closure
- Single layer aponeurotic closure: the incision is closed by suturing only the abdominal fascia in one layer.

Statement	Continuous suturing for closure of midline abdominal wall incisions in elective surgery is recommended.	☒☒☐☐	strong
Statement	Closure of the peritoneum as a separate layer during closure of laparotomy incisions is NOT recommended.	☒☒☐☐	weak

Statement	For closure of midline abdominal wall incisions in elective surgery, a single layer aponeurotic closure is suggested.	☒☐☐☐	weak

Suture length to wound length ratio (SL/WL)

The beneficial effect of a high SL/WL ratio on reducing the incidence of incisional hernias has been recognised for a long time [66], but evidence from clinical prospective studies remains scarce and most of the work addressing the topic comes from the Clinic of Sundsvall in Sweden [64, 67, 68]. A RCT, performed in Sundsvall, demonstrated the importance of the SL/WL ratio in reducing incisional hernia rate. The critical value was determined to be at a ratio of 4/1 [64]. Although a SL/WL ratio ≥4 is often mentioned in the protocol of prospective studies, many fail to document that the SL/WL ratio was recorded for the individual study patients.

Statement	A suture to wound length ratio (SL/WL) of at least 4/1 for continuous closure of midline abdominal wall incisions in elective surgery is suggested.	☒☒☐☐	weak
Statement	It is recommended that all prospective studies on the closure of laparotomy incisions will document the suture to wound length ratio (SL/WL) in all patients, as well as the number of stitches.		strong

Small bites versus large bites

Millbourn et al. [69] demonstrated that closure of a midline laparotomy with a "small bites" technique resulted in significant less incisional hernias (5.6 vs 18.0 %; $p < 0.001$) and less surgical site infections (5.2 vs 10.2 %; $p = 0.02$). In the small bite technique the laparotomy wound is closed with a single layer aponeurotic suturing technique taking bites of fascia of 5–8 mm and placing stitches every 5 mm.

Statement	The "small bites technique" for continuous closure of midline incisions is suggested.	☒☒☒☐	weak

What is the optimal suture material to close a laparotomy incision?

The PRISMA flow diagram for our search on suture materials is shown in Addendum 3 (Key Question H–K). Despite significant heterogeneity and confounders in most systematic reviews identified, a study by Sajid et al. [43] focused solely on the suture material. Table 3 defines the suture materials used in the included studies.

Rapidly absorbable suture versus non-absorbable or slowly absorbable sutures

Diener et al. [1] reported a significantly lower incisional hernia rate with slowly absorbable sutures (OR 0.65: $p = 0.009$) in elective surgery. Subgroup analysis performed by van't Riet et al. [48] comparing only continuous suturing studies, detected only one RCT by Wissing et al. [70] using continuous suturing in both study arms. This study, which included 21 % of emergency operations, showed significantly more incisional hernias with rapidly absorbable sutures compared to non-absorbable sutures ($p = 0.001$) and compared to slowly absorbable sutures ($p = 0.009$).

Statement	The use of rapidly absorbable suture material for closure of midline abdominal wall incisions in elective surgery is NOT recommended.	☒☒☒☐	strong

Non-absorbable versus slowly absorbable sutures

No difference in incisional hernia rate for continuous suturing of midline incisions with slowly absorbable versus non-absorbable sutures ($p = 0.75$) was identified [48]. However, an increased incidence of prolonged wound pain ($p < 0.005$) and suture sinus formation ($p = 0.02$) with non-absorbable sutures was reported [48]. Another meta-analysis (which included non-midline incisions) identified no difference in incisional hernia rate between slowly absorbable polydioxanone and non-absorbable sutures (OR 1.10: $p = 0.43$) [43]. Once again, non-absorbable sutures had a significant higher risk of suture sinus formation (OR 0.49: $p = 0.01$) [43].

Statement	Using slowly-absorbable suture material instead of non-absorbable sutures for continuous closure of midline abdominal wall incisions in elective surgery is suggested.	☒☒☐☐	weak

Monofilament versus multifilament sutures

Monofilament sutures are believed to be associated with a lower surgical site infection rate than multifilament sutures [12]. However, none of the systematic reviews commented on this issue specifically. If the previous recommendation to use slowly absorbable sutures for closure of elective midline laparotomies is followed, this question becomes superfluous because the slowly absorbable sutures are all monofilament sutures.

Statement	We suggest using monofilament suture material for continuous closure of midline abdominal wall incisions in elective surgery.	☒☐☐☐	weak

Concerning the size of the suture, no studies comparing directly the size of the sutures used to close abdominal wall incisions were identified during our searches. For the "small bites" technique, Isrealsson et al. [12] suggest to use a suture size USP 2/0 (USP = United States Pharmacopeia).

Statement	No recommendation on the size of the sutures for closure of abdominal wall incisions can be given due to lack of data.	☒☐☐☐	no

Sutures impregnated with antibiotics

Sutures coated with Triclosan as an antimicrobial agent have been introduced to decrease the rate of surgical site infection in surgery. A recent meta-analysis has demonstrated a significant beneficial effect in the prevention of surgical site infection after all kinds of surgery [71]. Surgical site infection is a risk factor for subsequent development of incisional hernias and therefore the use of antibiotics impregnated sutures to close laparotomies might be beneficial in the prevention of incisional hernias. Recently Diener et al. [72] published a large RCT on 1,224 patients undergoing an elective midline laparotomy comparing polydioxanone sutures with versus without triclosan impregnation. No reduction in the incidence of surgical site infection was reported (OR 0.91: CI 0.66–1.25; $p = 0.39$). Four other RCT's have compared sutures with or without triclosan in laparotomy closure, either with polyglactin sutures (Vicryl) [73, 74] or with polydioxanone (PDS) [75, 76]. A meta-analysis on all five studies performed by Diener et al. showed a significant decrease in surgical site infection (OR 0.67: CI 0.47–0.98). No data on incisional hernias are available from these studies.

Statement	Monofilament sutures impregnated with antibiotics for closure of elective midline incisions is NOT advised, because of insufficient data on their efficiency on prevention of surgical site infections and the lack of data on incisional hernias or burst abdomen.	☒☒☒☐	weak

Limitations of the statements in these guidelines on suture technique and suture materials

The statements are limited by the quality of the data on which they are based. In total, 61 RCT's have been identified that compared suture materials or techniques to close laparotomy incisions. Many studies have more than one variable between study arms and therefore, analysing them in meta-analyses is difficult. Moreover, many studies have flaws in the methodology increasing the risk of bias. We would like to encourage researchers that plan studies on abdominal wall closure to improve the methodology of their study protocol. Preferably, study arms are only different in the variable under investigation, either a suture technique or a suture material. Moreover, we recommend documenting the technical details such as SL/WL ratio, the number of stitches used in the patients and to provide a follow-up of at least 24 months.

Although some of the systematic reviews detected included non-midline incisions [43] or emergency operations [48], these guidelines are currently limited to elective midline laparotomies. For emergency operations and non-midline incisions there is currently not enough data available.

Suture needles and retention sutures

Blunt tip versus sharp needles

Only one systematic review assessing the type of needle used to close the abdominal wall [23] and one RCT comparing blunt needles with sharp needles were identified. The PRISMA flow diagram is shown in Addendum 3 (Key Question L). The RCT reported no difference in SSI rate between blunt and sharp needles [77].

Statement	No recommendation on the type or the size of needle to close a laparotomy can be given due to lack of data.	☒☐☐☐	no

Is there a place for retention sutures when closing a laparotomy?

No systematic review on the use of retention sutures was found. The PRISMA flow diagram of our additional search is shown in Addendum 3 (Key Question M). Eight records were screened by full text [78–85]. Three RCTs on the prevention of burst abdomen using either retention sutures or a reinforced tension line suture in patients with increased risk for wound dehiscence and burst abdomen were identified [78–80]. Follow-up was too short to evaluate incisional hernia rate. The Summary of Findings is listed in Table 4. Two studies showed favourable results [78, 79], but one study reported a high number of adverse events when using retention sutures [80].

Statement	No recommendation on suture material or suturing technique for use in emergency surgery can be given due to lack of sufficient data.	☒☐☐☐	no
Statement	No recommendation on suture material or suturing technique for use in non-midline incisions can be given due to lack of sufficient data.	☒☐☐☐	no

Statement	No recommendation on the use of retention sutures in patients with multiple risk factors for burst abdomen can be given due to insufficient data.	☒☒☐☐	no

Table 3 List of the most commonly used suture materials to close abdominal wall incisions and their characteristics

	Producer	Material	Absorbable	Absorption time	Mono/multifilament	Antibiotics impregnated
Prolene	Ethicon	Polypropylene	Non		Monofilament	No
Surgipro	Covidien	Polypropylene	Non		Monofilament	No
Ethilon	Ethicon	Nylon	Non		Monofilament	No
Monosof	Covidien	Nylon	Non		Monofilament	No
Ethibond	Ethicon	Polyethylene	Non		Multifilament	No
Mersilene	Ethicon	Polyester	Non		Multifilament	No
Surgilon	Covidien	Nylon	Non		Multifilament	No
Maxon	Covidien	Polyglyconate	Slowly	180 days	Monofilament	No
PDS	Ethicon	Polydioxanone	Slowly	183–238 days	Monofilament	No
PDS plus	Ethicon	Polydioxanone + triclosan	Slowly	183–238 days	Monofilament	Yes
Monoplus	B Braun	Polydioxanone	Slowly	180–201 days	Monofilament	No
Monomax	B Braun	Poly-4-hydroxybutyrate	Slowly	390–1080 days	Monofilament	No
Vicryl	Ethicon	Polyglactin	Rapidly	56–70 days	Multifilament	No
Vicryl plus	Ethicon	Polyglactin + triclosan	Rapidly	56–70 days	Multifilament	Yes
Polysorb	Covidien	Polyglycolic acid	Rapidly	60–90 days	Multifilament	No
Dexon	Covidien	Polygglycolic acid	Rapidly	60–90 days	Multifilament	No

Postoperative care

Postoperative management and instructions for patients are not supported by high quality prospective data, but rely mostly on surgeons' habits, tradition and common beliefs [86–88]. Long-term follow-up studies are needed to research the impact on the occurrence of incisional hernias of prescribing abdominal binders or restricting postoperative activity. The additional searches as shown in PRISMA flow diagrams in Addendum 3 (Key Question N, O, P) did not reveal any relevant study on long-term outcome. Some studies on the short-term benefits of abdominal binders were found.

Subcutaneous drains in laparotomy incisions

Prophylactic routine placement of subcutaneous drains after laparotomy is occasionally used to decrease wound complications: infection, hematoma, seroma or wound dehiscence [86]. However, there are several disadvantages to the routine use of subcutaneous drains. Namely, they cause patient discomfort and pain at removal, they hinder early mobilisation and demand additional nursing care. Therefore, their use should be driven by a proven benefit.

One systematic review [89] and several RCTs [90–98] on the use of subcutaneous drains in abdominal surgery were found. They cover a wide range of operative indications: liver surgery, colorectal surgery, cholecystectomy, gynaecological surgery, caesarean section, and gastric bypass surgery. With few exceptions, most studies did not show a benefit for the use of subcutaneous drains. However, none of these studies had incisional hernias or burst abdomen as primary or secondary endpoint.

Statement	The routine placement of a subcutaneous drain during closure of abdominal wall incisions is NOT recommended.	☒☒☒☐	strong

Table 4 Summary of Findings table for Key Question M: is there a place for retention sutures when closing a laparotomy?

Bibliographic citation [reference]	Study type	Number of patients	Patient characteristics	Intervention	Comparison	Length of follow-up	Outcome measure
Khorgami et al. J Surg Res. 2013;180:238–43 [78]	RCT	300	Patients undergoing midline laparotomy with ≥2 risk factors of a list of defined risk factors for burst abdomen	Extra retention sutures Nylon 1 (every 10 cm and with 5 cm bites of skin) kept for 3–4 weeks	Continuous loop size 1 nylon suture (1 cm from the edge/1 cm intervals)	Median 5 months	Wound dehiscence was 4.1 % (6/147) in the intervention group and 13.5 % (20/148) in the control group ($p = 0.007$). "We showed that prophylactic retention sutures could reduce wound dehiscence in midline laparotomy in high-risk patients with multiple risk factors without imposing remarkable postoperative complications."
Agrawal Trop Gastroenterol 2009;30:237–40 [79]	RCT	190	Emergency midline laparotomy	Reinforced tension line suture	Continuous suture		Burst abdomen was 0.0 % (0/90) in the intervention group and 13.0 % (13/100) in the control group ($p = 0.0026$). "Closure of midline incision by RTL reduces the incidence of burst abdomen."
Rink et al. Eur J Surg. 2000;166:932–7 [80]	RCT	95 (92 midline)	Patients needing major abdominal surgery with infective or malignant intra-abdominal diseases. + at least one risk factor	Extra retention sutures with sutures retention bridge for 12 days	Interrupted Vicryl 1 sutures	12 days	"Retention sutures used to close abdominal wounds cause inconvenience, pain, and specific morbidity"

Postoperative binders

One systematic review on the use of abdominal binders was found [87]. The review included four RCT's [99–102] and a national survey by questionnaire on the use of abdominal binders in French surgical practice [87]. One additional recent RCT was identified [103].

The French survey reported that postoperative support of the wound with an abdominal binder is common practice after major laparotomies in many surgical departments (94 % use them in some patients). It is expected to reduce postoperative pain and to improve early mobilisation of the patients. Moreover, 83 % of users expect a benefit in the prevention of abdominal wall dehiscence [87].

No significant improvement for the short-term benefits was found by the small RCTs from the review [98–101]. The additional study by Clay et al. [102] found a significant lower Visual Analogue Scale (VAS) score for pain at the fifth postoperative day and no adverse effect on postoperative lung function. No studies were found that had burst abdomen or incisional hernias as primary or secondary endpoints.

Statement	No recommendation can be given on the use of postoperative abdominal binders due to lack of data on their effect on incisional hernias or burst abdomen rates.	☒☐☐☐	no

Postoperative restriction of activity

No prospective studies were found on the restriction of physical activity after abdominal incisions. Nevertheless, it is advocated by some surgeons to decrease the risk of incisional hernias, but there is no consensus on the level or the duration of the restriction [88]. Postoperative restriction might have an adverse impact on the return to normal activity and delay the return to work.

Statement	No recommendation can be given on routine restriction of activity after abdominal surgery due to lack of data on the effect on incisional hernias or burst abdomen rates.	☒☐☐☐	no

Prophylactic mesh augmentation

The PRISMA flow diagram for prophylactic mesh augmentation is shown in Addendum 3 (Key Question Q–T). Three systematic reviews on the topic were found [24, 39, 104].

1. Nachappian et al. [39] did not assess of the quality of the individual studies and included non published data. Therefore, this review did not qualify for inclusion in this guideline.
2. The systematic review by Bhangu et al. [24] is of High Quality and offers a good and extensive evaluation of the quality of the individual studies included. However, the quality of the non RCTs was usually low and these studies were not used as evidence for these guidelines.
3. Timmermans et al. [104] published a good meta-analysis on five RCT's using polypropylene mesh, including a RCT published in 2013 by Abo-Ryia et al. [105].

One additional RCT published after the review by Timmermans et al. [106] was identified. In this RCT, one hundred and sixty patients were included. This is the first trial on non-selected elective midline laparotomies (with a majority of oncological patients). All the other trials have only included patients deemed at high risk for incisional hernias. In this RCT by Caro-Tarrago et al. the mesh augmentation was performed with a light weight polypropylene mesh in the onlay position. A significant reduction in incisional hernias at 12 months was observed clinically and with CT scan in favour of prophylactic mesh, 1.5 vs 35.9 % ($p < 0.0001$). A significantly higher number of postoperative seroma was detected in the mesh group, 11.3 vs 28.8 % ($p < 0.01$). No major complications related to the mesh augmentation were reported.

The details of the six published RCT's using polypropylene mesh including 506 patients are listed in Table 5 [105–110]. Using Review Manager 5.2 software a new meta-analysis was performed. The data for this meta-analysis were extracted from the Timmermans et al. meta-analysis and the additional RCT [104, 106]. A meta-analysis on the outcomes of incisional hernia, seroma and SSI was performed. The pooled analyses data are shown in a Forrest plot for each outcome in Fig. 2. Prophylactic mesh augmentation is effective in the prevention of incisional hernias (RR 0.17: CI 0.08–0.37). An increased incidence of postoperative seroma is identified, but the majority of these

Table 5 List of the randomized clinical trials and their characteristics on prophylactic mesh augmentation using a polypropylene mesh

RCT [reference]	Publ. date	LoE	SIGN	*n*	Population	Mesh position	FU months	Incisional hernias			Effect size
								Diagnosis incisional hernia	NO mesh	Mesh	Risk ratio (95 % CI)
Gutiérrez [107]	2003	2b	+	88	High risk patients	Onlay	36	Clinical + selective CT scan	5/44	0/44	0.09 (0.01–1.60)
Strelczyk [108]	2006	1b	++	74	Obesity surgery	Retro-muscular	28	Clinical + ultrasound in all	8/38	0/36	0.06 (0.00–1.04)
El-Kadrawy [109]	2009	2b	+	40	High risk patients	Pre-peritoneal	36	Clinical	3/20	1/20	0.33 (0.04–2.94)
Bevis [110]	2010	1b	++	80	AAA	Retro-muscular	25.4	Clinical + selective ultrasound	16/43	5/37	0.36 (0.15–0.90)
Abo-Ryia [105]	2013	2b	+	64	Obesity surgery	Pre-peritoneal	48	Clinical + selective ultrasound	9/32	1/32	0.11 (0.01–0.83)
Caro-Tarrago [106]	2014	1b	++	160	Midline laparotomies	Onlay	12	Clinical + CT scan in all	30/80	2/80	0.07 (0.02–0.27)
Overall				506					71/257	9/249	0.17 (0.08–0.37)

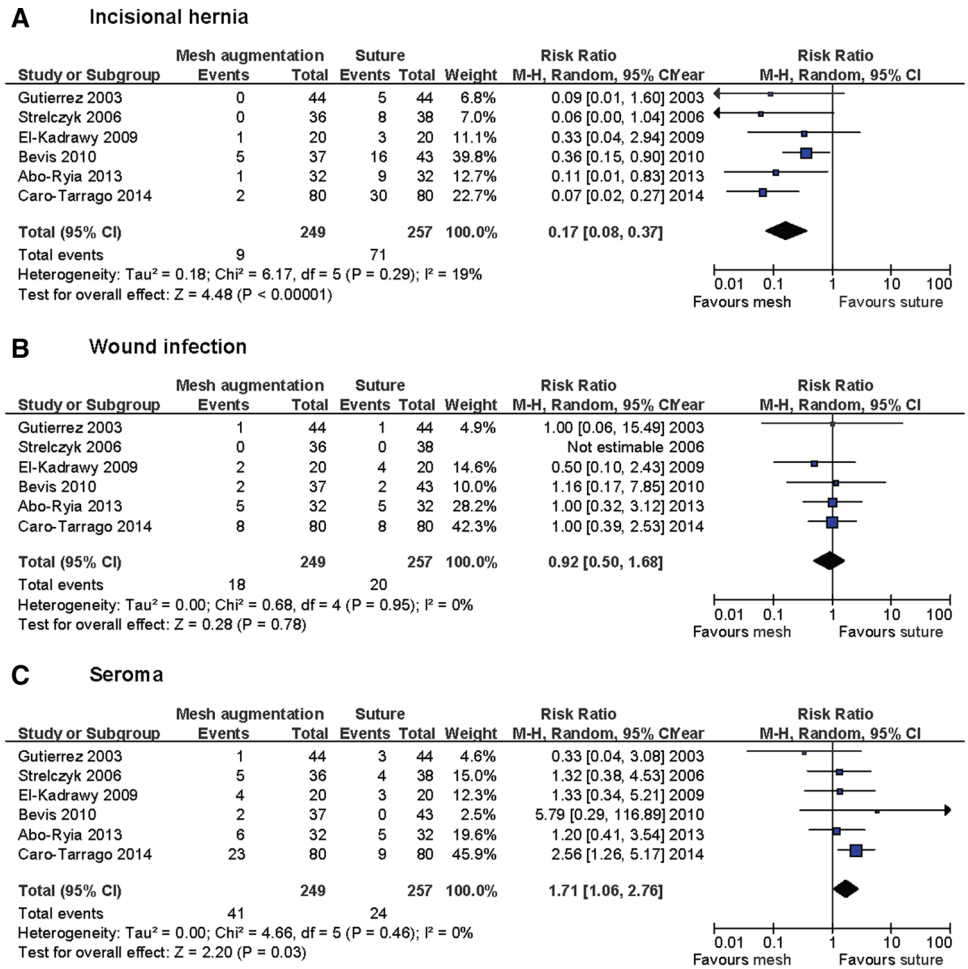

Fig. 2 Forrest plots of a meta-analysis performed by the Guidelines Development Group on prophylactic mesh augmentation with polypropylene mesh after laparotomy. Analysis on the outcomes of incisional hernia, seroma and surgical site infection was performed

are from the single study by Caro-Tarrago et al. [106] where the mesh was placed in an onlay position, with a weight of 45.9 % on the cumulative Risk Ratio for seroma (RR = 1.71; 95 %CI: 1.06–2.76) (Fig. 2c).

Although the data are favourable and consistent for prophylactic mesh augmentation, the Guidelines Development Group decided that larger trials are needed to make a strong recommendation to perform prophylactic mesh augmentation for all patients within certain risk groups.

Statement	Prophylactic mesh augmentation for an elective midline laparotomy in a high-risk patient in order to reduce the risk of incisional hernia is suggested.	☒☒☒☐	weak

Which mesh type, which mesh position and which type of mesh fixation?

No comparative studies are published between different mesh type, mesh position or method of mesh fixation. Pans et al. [111] found no significant protective effect on incisional hernia rate by intra-peritoneal augmentation with a polyglactin mesh (Vicryl; Ethicon) on incisional hernia rate in a RCT on obesity surgery ($n = 288$). Llaguna et al. [112] placed a biological mesh (Alloderm; LifeCell) in a retro-muscular position in bariatric patients. In this non-randomised comparative study ($n = 106$ of which 44 with mesh) a significantly lower incisional hernia rate was observed in the mesh group, 2.3 vs 17.7 % ($p = 0.014$). All other studies published used a polypropylene mesh, most often a small pore/heavy weight mesh: Prolene; Ethicon [110], Premilene; B. Braun [107], no name mentioned [105, 108, 109]. Only Caro-Tarrago et al. [106] used a large pore/light weight mesh: Biomesh Light P8; Cousin Biotech.

There is a large variation between the studies on the mesh position for the prophylactic mesh augmentation. Onlay, retro-muscular and pre-peritoneal mesh positioning was performed in two studies each. No studies on the use of intra-peritoneal augmentation with a non absorbable synthetic mesh are reported. Only one study on the use of intra-peritoneal augmentation with an absorbable synthetic mesh is reported [111]. The mesh was in all studies fixed with sutures to the fascia except for the study of Pans et al. [111] which used no fixation. No studies on mesh augmentation with glue or a self-fixating mesh are reported.

Statement	No recommendation on the optimal mesh position for prophylactic mesh augmentation can be given due to lack of data.	☒☐☐☐	no
Statement	No recommendation on the optimal method of mesh fixation for prophylactic mesh augmentation can be given due to lack of data.	☒☐☐☐	no
Statement	No recommendation on the type of mesh for prophylactic mesh augmentation can be given due to lack of data.	☒☐☐☐	no

Trocar wounds for laparoscopic surgery and single port surgery

The PRISMA flow diagram for the Key Questions on laparoscopic surgery and single incision surgery are shown in Addendum 3 (Key Question U–W and K, Q, X).

Trocar size and trocar type

The first search for systematic reviews resulted in five records [33, 40, 41, 46, 49] and 25 additional records were screened by full text [113–137]. Several studies comment on the incidence of trocar-site hernia for various trocar sizes. However, the quality of many studies is insufficient and challenges the validity of results. Shortcomings of the individual studies include retrospective study design, short or unclear length of follow-up and inappropriate or no information on diagnostic methods to detect incisional hernias. Most importantly, available data derive from studies in which the same patient serves as case and control; i.e. the incidence of trocar-site hernia is measured for different sizes of trocars inserted at different abdominal sites in the same patient. This may impose significant bias, related to the strength of the abdominal wall and the wound repair mechanisms at varying sites of the abdominal wall, in particular the linea alba to other parts of the abdominal wall.

Helgstrand et al. [33] performed a systematic review on the incidence of trocar-site hernia. Although they found a risk reduction after sutured closure and a lower hernia rate for 5-mm versus larger diameter trocars, no meta-analysis was undertaken. The poor quality and design of the majority of the included reports preclude further in-depth evaluation for supporting evidence. No RCT's have investigated the incidence of trocar-site hernia after

insertion of blunt versus bladed trocars and no RCT's or case-control studies have investigated the incidence of trocar-site hernia with reference to trocar size or diameter. Available data derived from univariate and multivariate analyses of cohort studies, which have investigated the effect of potential risk factors for trocar-site hernia. Obesity, age above 60 years diabetes, long duration of surgery, and the need for fascia enlargement for specimen extraction were identified as risk factors for the development of trocar-site hernia [120, 137].

Statement	Emerging evidence suggests an increased incidence of trocar-site hernia for single-incision surgery as compared to conventional surgery; therefore meticulous closure of the incised fascia in single-port surgery is recommended.	☒☒☒☐	weak

Statement	For laparoscopic procedures, using the smallest trocar size adequate for the procedure is suggested.	☒☒☐☐	weak
Statement	For laparoscopic procedures, suturing the fascial defect, if trocars larger than or equal to 10 mm have been used, in the presence of established risk factors for incisional hernia formation is suggested.	☒☐☐☐	weak

Closure of trocar incisions

There are no good quality comparative studies investigating different suture materials or techniques for closure of trocar fascia defects. Armananzas et al. [113] reported in a recently published RCT a benefit for prophylactic intraperitoneal placement of a ventral patch at the umbilical site in high-risk patients to reduce the incidence of trocar-site hernia from 18.5 to 4.4 % (OR 10.1: CI 2.15–47.6; $p < 0.001$). Larger sample-sized studies with a good risk–benefit assessment and longer follow-up are needed to confirm and support a stronger recommendation.

Statement	For laparoscopic procedures a mesh-augmented closure may be applied in patients at high risk for trocar-site hernia.	☒☒☒☐	weak

Single incision laparoscopic surgery and incisional hernia

The incidence of trocar-site hernia after single port surgery has been mostly investigated as a secondary outcome measure in the setting of RCTs and 3 High Quality meta-analyses were found [138–140]. Two meta-analyses of RCTs have found no difference in the incidence of trocar-site hernia between single port and multiple port surgery, although a trend in favour of multiple port surgery was demonstrated [138, 139]. The most recent meta-analysis included 19 RCTs involving 676 patients and found a higher incidence of trocar site hernia following single port surgery [140].

Discussion

Key results

A list of the statements from these guidelines is provided in Addendum 4 as a PDF file.

Limitations

Not many strong recommendations could be made due to lack of sufficient evidence on many of the PICO questions.

It is somewhat confusing to notice that the first strong recommendation in these guidelines is to avoid midline laparotomies in favour of alternative incisions and that all other recommendations are only valid for elective midline incisions. Indeed most research is focused on midline laparotomies. A midline laparotomy is still the favoured

approach for most surgeons. It allows quick entrance to the abdominal cavity and extension of the incision is easy if this is required for the operation. Nevertheless, the linea alba is probably the most vulnerable and least vascularized part of the abdominal wall. Some refer to incisional hernias as "a midline crisis". Optimising closure of abdominal wall incisions would appear to hold a large potential in reducing the incidence of incisional hernias and the subsequent need for incisional hernia repair. This has obvious benefits for the individual patient relating to an improved quality of life, avoidance of secondary operations and at a macro-economical level a significant reduction in costs for health care resources. It is not easy to see the impact of each recommendation separately. Therefore, implementation of the optimised abdominal wall closure is probably best done by teaching all involved specialists a standardised technique described as the "Principles" of abdominal wall closure [17]. This incorporates all recommendations, although the Guidelines Development Group is aware that the level of evidence for the different aspects is sometimes low to very low. David Sackett, a pioneer in evidence-based medicine wrote: "…any external guideline must be integrated with individual clinical expertise in deciding whether and how it matches the patient's clinical state, predicament, and preferences, and thus whether it should be applied". [141].

Discussions

For most Key Questions on the technique and material to close abdominal wall incisions, the grading of the Quality of Evidence and the choice of recommendation was straightforward. For several recommendations, while the quality of evidence was low, there was good consensus between the members of the Guidelines Development Group on the formulated statements. For prophylactic mesh augmentation there was disagreement on the strength of recommendation (weak or strong). For this reason, an additional meta-analysis was performed (Fig. 2). Although the effect size in favour of mesh augmentation is large and consistent over the studies, the Guidelines Development Group felt that larger trials are needed to support a strong recommendation for prophylactic mesh augmentation in high-risk patients. Indeed, the number of patients in the reported studies for each risk group separately (e.g. abdominal aortic aneurysm, obesity surgery, oncological surgery) seems too low to recommend prophylactic mesh augmentation in all these patient groups. Nevertheless, we are aware that several large RCT's are on-going and this grade of recommendation might be changed in the light of future publications.

No recommendations could be made on non-midline incisions due to insufficient evidence. Nevertheless, it seems reasonable to promote similar material (slowly absorbable suture) and techniques (continuous aponeurotic closure with small bites and SL/WL >4/1) for closure of non-midline incisions.

No recommendations could be made on the type or the size of the needle used to close abdominal incisions. No studies comparing the size of the sutures were identified in our searches.

No recommendation could be made for emergency surgery, which is often a contaminated procedure. The Guidelines Development Group consider that the use of retention sutures or of reinforced tension line sutures, should be prospectively studied in patients at high risk for development of burst abdomen. A risk model and score for burst abdomen has been developed by van Ramshorst et al. [142] and could be used as basis for including patients in these studies.

No recommendations could be made on the postoperative care after laparotomies. Long-term follow-up studies are needed to assess the impact on the occurrence of incisional hernias of prescribing abdominal binders or restricting or indeed encouraging early postoperative activity.

Applicability

To adopt the guidelines and "evidence based principles" for abdominal wall closure, surgeons must be convinced that these are valid recommendations with a large impact on the outcome for the patients. These guidelines are an attempt to create awareness amongst surgeons about these principles. Adaptation can be done by systematic quality control of the suturing technique as described by van Ramshorst et al. [143]. The EuraHS, European registry for abdominal wall hernias, has developed an online platform for registration and outcome measurement of abdominal wall surgery [144]. An additional route in the database on the closure of abdominal wall incisions and for prophylactic mesh augmentation will be provided from 2015 onwards. It is hoped that such a registry database will facilitate the data collection for prospective studies.

Validity of the guidelines

Prior to submission of the manuscript the guidelines were evaluated and scored using the AGREE II instrument. The results of these assessments are presented in Table 6. Several large multi-centre studies on the closure of abdominal wall incisions are currently on-going. High Quality data on the use of the "small bites" technique in midline incisions, on the closure of laparotomies in emergency and on prophylactic mesh augmentation will be published in the coming years. The Guidelines Development Group has decided to update these guidelines in 2017

Table 6 Results of the scoring of the guidelines by external experts using the AGREE II instrument [20]. Each item is scored between 1 (=strongly disagree) and 7 (=strongly agree). For each domain a scaled domain score is given as a percentage

Domain 1: Scope and purpose				
Scaled domain score = 90.3 %				
	Item 1	Item 2	Item 3	Total
Appraiser 1	7	5	5	17
Appraiser 2	7	7	7	21
Appraiser 3	6	6	6	18
Appraiser 4	7	7	7	21
Total	27	25	25	77
Domain 2: Stakeholder involvement				
Scaled domain score = 76.4 %				
	Item 4	Item 5	Item 6	Total
Appraiser 1	6	3	5	14
Appraiser 2	7	5	7	19
Appraiser 3	6	4	4	14
Appraiser 4	6	7	7	20
Total	25	19	23	67

Domain 3: Rigour of development									
Scaled domain score = 85.9 %									
	Item 7	Item 8	Item 9	Item 10	Item 11	Item 12	Item 13	Item 14	Total
Appraiser 1	7	7	6	6	5	6	7	4	48
Appraiser 2	7	7	7	7	6	6	7	6	53
Appraiser 3	6	6	6	5	4	4	5	4	40
Appraiser 4	7	7	7	7	7	7	7	7	56
Total	27	27	26	25	22	23	26	21	197

Domain 4: Clarity of presentation				
Scaled domain score = 87.5 %				
	Item 15	Item 16	Item 17	Total
Appraiser 1	7	5	6	18
Appraiser 2	7	7	7	21
Appraiser 3	5	5	5	15
Appraiser 4	7	7	7	21
Total	26	24	25	75

Domain 5: Applicability					
Scaled domain score = 52.1 %					
	Item 18	Item 19	Item 20	Item 21	Total
Appraiser 1	5	4	5	4	18
Appraiser 2	4	3	3	1	11
Appraiser 3	3	3	3	4	13
Appraiser 4	7	7	7	3	24
Total	19	17	18	12	66

Table 6 continued

Domain 6: Editorial independence			
Scaled domain score = 95.8 %			
	Item 22	Item 23	Total
Appraiser 1	7	7	14
Appraiser 2	7	7	14
Appraiser 3	6	6	12
Appraiser 4	7	7	14
Total	27	27	54

Overall assessment		
	Rating of the overall Quality of the guideline	I would recommend this guideline for use
Appraiser 1	6	Yes
Appraiser 2	6	Yes
Appraiser 3	5	Yes
Appraiser 4	7	Yes

and present the results during the 39th Annual Congress of the European Hernia Society in Vienna in May 2017.

Conclusions

To decrease the incidence of incisional hernias it is recommended to utilise a non-midline approach to a laparotomy whenever possible. For elective midline incisions, it is strongly recommended to perform a continuous suturing technique and to avoid the use of rapidly absorbable sutures. It is suggested that the use of a slowly absorbable monofilament suture in a single layer aponeurotic closure technique without separate closure of the peritoneum and using a small bites technique with a SL/WL ratio at least 4/1 is the current recommended method of fascial closure. Currently, no recommendations can be given on the optimal technique to close emergency laparotomy incisions. Prophylactic mesh augmentation appears effective and safe and can be suggested in high-risk patients like, aortic aneurysm surgery and obese patients.

Other information

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Conflict of interest The authors report no conflict of interest in relation to this manuscript.

References

1. Diener MK, Voss S, Jensen K, Buchler MW, Seiler CM (2010) Elective midline laparotomy closure: the inline systematic review and meta-analysis. Ann Surg 251:843–856
2. Fink C, Baumann P, Wente MN, Knebel P, Bruckner T, Ulrich A, Werner J, Büchler MW, Diener MK (2014) Incisional hernia rate 3 years after midline laparotomy. Br J Surg 101:51–54
3. Pereira JA, Pera M, Grande L (2013) Incidence of incisional hernia after open and laparoscopic colorectal cancer resection (Spanish language). Cir Esp 91:44–49
4. Claes K, Beckers R, Heindryckx E, Kyle-Leinhase I, Pletinckx P, Claeys D, Muysoms F (2014) Retrospective observational study on the incidence of incisional hernias after colorectal carcinoma resection with follow-up CT scan. Hernia Jan 21 (Epub ahead of print)
5. den Hartog D, Dur AHM, Kamphuis AGA, Tuinebreijer WE, Kreis RW (2009) Comparison of ultrasonography with

computed tomography in the diagnosis of incisional hernias. Hernia 13:45–48
6. Bloemen A, Van Dooren P, Huizinga BF, Hoofwijk AGM (2012) Comparison of ultrasonography and physical examination in the diagnosis of incisional hernia in a prospective study. Hernia 16:53–57
7. Bosanquet D, Aboelrahman T, Ansell J, Cornish J, Davies L, Frewer K, Frewer N, Glasbey J, Harries R, Stimpson A, Russell D, Russell I, Torkington J (2014) Systematic review and meta regression of factors affecting midline incisional hernia rates: an analysis of 14,618 patients. Hernia 18(suppl 2):S12–S15
8. Alnassar S, Bawahab M, Abdoh A, Guzman R, Al Tuwaijiri T, Louridas G (2012) Incisional hernia postrepair of abdominal aortic occlusive and aneurysmal disease: five-year incidence. Vascular 20:273–277
9. Höer J, Lawong G, Klinge U, Schumpelick V (2002) Factors influencing the development of incisional hernia. A retrospective study of 2,983 laparotomy patients over a period of 10 years. Chirurg 73:474–480
10. Antoniou GA, Georgiadis GS, Antoniou SA, Granderath FA, Giannoukas AD, Lazarides MK (2011) Abdominal aortic aneurysm and abdominal wall hernia as manifestations of a connective tissue disorder. J Vasc Surg 54:1175–1181
11. Henriksen NA, Helgstrand F, Vogt KC, Jorgensen LN, Bisgaard T (2013) Risk factors for incisional hernia repair after aortic reconstructive surgery in a nationwide study. J Vasc Surg 57:1524–1530
12. Israelsson LA, Millbourn D (2013) Prevention of incisional hernias: how to close a midline incision. Surg Clin North Am 93:1027–1040
13. van Ramshorst GH, Eker HH, Hop WC, Jeekel J, Lange JF (2012) Impact of incisional hernia on health-related quality of life and body image: a prospective cohort study. Am J Surg 204:144–150
14. Flum DR, Horvath K, Koepsell T (2003) Have outcomes of incisional hernia repair improved with time? A population-based analysis. Ann Surg 237:129–135
15. Burger JW, Luijendijk RW, Hop WC, Halm JA, Verdaasdonk EG, Jeekel J (2004) Long-term follow-up of a randomized controlled trial of suture versus mesh repair of incisional hernia. Ann Surg 240:578–583
16. Helgstrand F, Rosenberg J, Kehlet H, Strandfelt P, Bisgaard T (2012) Reoperation versus clinical recurrence rate after ventral hernia repair. Ann Surg 256:955–958
17. Meijer EJ, Timmermans L, Jeekel J, Lange JF, Muysoms FE (2013) The principles of abdominal wound closure. Acta Chir Belg 113:239–244
18. Data presented by J-F Gillion during the 36th Annual Congress of the European Hernia Society in Edinburgh on May 31st 2014. (Publication in preparation: J-F Gillion, D. Sanders, M. Miserez, F. Muysoms; The Bonham Group. The economic burden of incisional hernia repair.)
19. Scottish Intercollegiate Guidelines Network (SIGN). http://www.sign.ac.uk/
20. Brouwers M, Kho ME, Browman GP, Burgers JS, Cluzeau F, Feder G, Fervers B, Graham ID, Grimshaw J, Hanna S, Littlejohns P, Makarski J, Zitzelsberger L (2010) AGREE II: Advancing guideline development, reporting and evaluation in healthcare. Can Med Assoc J 182:E839–E842. http://www.agreetrust.org/
21. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, Clarke M, Devereaux PJ, Kleijnen J, Moher D (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J Clin Epidemiol 62:e1–e34. http://www.prisma-statement.org/
22. Guyatt GH, Oxman AD, Vist G, Kunz R, Falck-Ytter Y, Alonso-Coello P, Schünemann HJ (2008) Rating quality of evidence and strength of recommendations GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 336:924–926. http://www.gradeworkinggroup.org/
23. Anderson ER, Gates S (2004) Techniques and materials for closure of the abdominal wall in caesarean section. Cochrane Database Syst Rev 18:CD004663
24. Bhangu A, Fitzgerald JE, Singh P, Battersby N, Marriott P, Pinkney T (2013) Systematic review and meta-analysis of prophylactic mesh placement for prevention of incisional hernia following midline laparotomy. Hernia 17:445–455
25. Bhangu A, Nepogodiev D, Futaba K (2012) Systematic review and meta-analysis of the incidence of incisional hernia at the site of stoma closure. World J Surg 36:973–983
26. Bickenbach KA, Karanicolas PJ, Ammori JB, Jayaraman S, Winter JM, Fields RC, Govindarajan A, Nir I, Rocha FG, Brennan MF (2013) Up and down or side to side? A systematic review and meta-analysis examining the impact of incision on outcomes after abdominal surgery. Am J Surg 206:400–409
27. Brown SR, Goodfellow PB (2005) Transverse verses midline incisions for abdominal surgery. Cochrane Database Syst Rev 4:CD005199
28. Cheng H, Rupprecht F, Jackson D, Berg T, Seelig MH (2007) Decision analysis model of incisional hernia after open abdominal surgery. Hernia 11:129–137
29. Finan KR, Kilgore ML, Hawn MT (2009) Open suture versus mesh repair of primary incisional hernias: a cost-utility analysis. Hernia 13:173–182
30. Friedrich M, Muller-Riemenschneider F, Roll S, Kulp W, Vauth C, Greiner W, Willich S, von der Schulenburg JM (2008) Health technology assessment of laparoscopic compared to conventional surgery with and without mesh for incisional hernia repair regarding safety, efficacy and cost-effectiveness. GMS Health Technol Assess 4:Doc01
31. Grantcharov TP, Rosenberg J (2001) Vertical compared with transverse incisions in abdominal surgery. Eur J Surg 167:260–267
32. Gupta H, Srivastava A, Menon GR, Agrawal CS, Chumber S, Kumar S (2008) Comparison of interrupted versus continuous closure in abdominal wound repair: a meta-analysis of 23 trials. Asian J Surg 31:104–114
33. Helgstrand F, Rosenberg J, Bisgaard T (2011) Trocar site hernia after laparoscopic surgery: a qualitative systematic review. Hernia 15:113–121
34. Hodgson NC, Malthaner RA, Ostbye T (2000) The search for an ideal method of abdominal fascial closure: a meta-analysis. Ann Surg 231:436–442
35. Hynes DM, Stroupe KT, Luo P, Giobbie-Hurder A, Reda D, Kraft M, Itani K, Fitzgibbons R, Jonasson O, Neumayer L (2006) Cost effectiveness of laparoscopic versus open mesh hernia operation: results of a department of veterans affairs randomized clinical trial. J Am Coll Surg 203:447–457
36. Mathai M, Hofmeyr GJ, Mathai NE (2013) Abdominal surgical incisions for caesarean section. Cochrane Database Syst Rev 5:CD004453
37. Jin JB, Jiang ZP, Chen S (2010) Meta-analysis of suture techniques for midline abdominal incisions. Zhonghua Wai Ke Za Zhi [Chinese J Surg] 48:1256–1261
38. Le Huu Nho R, Mege D, Ouaïssi M, Sielezneff I, Sastre B (2012) Incidence and prevention of ventral incisional hernia. J Visc Surg 149(5 Suppl):e3–e14
39. Nachiappan S, Markar S, Karthikesaligam A, Ziprin P, Faiz O (2013) Prophylactic mesh placement in high-risk patients undergoing elective laparotomy: a systematic review. World J Surg 37:1861–1871

40. Owens M, Barry M, Janjua AZ, Winter DC (2011) A systematic review of laparoscopic port site hernias in gastrointestinal surgery. Surgeon 9:218–224
41. Pemberton RJ, Tolley DA, van Velthoven RF (2006) Prevention and management of complications in urological laparoscopic port site placement. Eur Urol 50:958–968
42. Rucinski J, Margolis M, Panagopoulos G, Wise L (2001) Closure of the abdominal midline fascia: meta-analysis delineates the optimal technique. Am Surg 67:421–426
43. Sajid MS, Parampalli U, Baig MK, McFall MR (2011) A systematic review on the effectiveness of slowly-absorbable versus non-absorbable sutures for abdominal fascial closure following laparotomy. Int J Surg 9:615–625
44. Seiler CM, Bruckner T, Diener MK, Papyan A, Golcher H, Seidlmayer C, Franck A, Kieser M, Bücher MW, Knaebel HP (2009) Interrupted or continuous slowly absorbable sutures for closure of primary elective midline abdominal incisions: a multicenter randomized trial. Ann Surg 249:576–582
45. Seiler CM, Deckert A, Diener MK, Knaebel HP, Weigand MA, Victor N, Büchler MW (2009) Midline versus transverse incision in major abdominal surgery: a randomized, double-blind equivalence trial. Ann Surg 249:913–920
46. Swank HA, Mulder IM, la Chapelle CF, Reitsma JB, Lange JF, Bemelman WA (2012) Systematic review of trocar-site hernia. Br J Surg 99:315–323
47. Takagi H, Sugimoto M, Kato T, Matsuno Y, Umemoto T (2007) Postoperative incision hernia in patients with abdominal aortic aneurysm and aortoiliac occlusive disease: a systematic review. Eur J Vasc Endovasc Surg 33:177–181
48. van 't Riet M, Steyerberg EW, Nellensteyn J, Bonjer HJ, Jeekel J (2002) Meta-analysis of techniques for closure of midline abdominal incisions. Br J Surg 89:1350–1356
49. Yamamoto M, Minikel L, Zaritsky E (2011) Laparoscopic 5-mm trocar site herniation and literature review. JSLS 15:122–126
50. Baucom RB, Beck WC, Holzman MD, Sharp KW, Nealon WH, Poulose BK (2014) Prospective evaluation of surgeon physical exam for detection of incisional hernia. J Am Coll Surg 218:363–366
51. Beck WC, Holzman MD, Sharp KW, Nealon WH, Dupont WD, Poulose BK (2013) Comparative effectiveness of dynamic abdominal sonography for hernia vs computed tomography in the diagnosis of incisional hernia. J Am Coll Surg 216:447–453
52. Schreinemacher MH, Vijgen GH, Dagnelie PC, Bloemen JG, Huizinga BF, Bouvy ND (2011) Incisional hernias in temporary stoma wounds: a cohort study. Arch Surg 146:94–99
53. Bhangu A, Fletcher L, Kingdon S, Smith E, Nepogodiev D, Janjua U (2012) A clinical and radiological assessment of incisional hernias following closure of temporary stomas. Surgeon 10:321–325
54. Cingi A, Cakir T, Sever A, Aktan AO (2006) Enterostomy site hernias: a clinical and computerized tomographic evaluation. Dis Colon Rectum 49:1559–1563
55. Cingi A, Solmaz A, Attaallah W, Aslan A, Aktan AO (2008) Enterostomy closure site hernias: a clinical and ultrasonographic evaluation. Hernia 12:401–405
56. Musella M, Milone F, Chello M, Angelini P, Jovino R (2001) Magnetic resonance imaging and abdominal wall hernias in aortic surgery. J Am Coll Surg 193:392–395
57. Rodriguez HE, Matsumura JS, Morasch MD, Greenberg RK, Pearce WH (2004) Abdominal wall hernias after open abdominal aortic aneurysm repair: prospective radiographic detection and clinical implications. Vasc Endovasc Surg 38:237–240
58. Hojer AM, Rygaard H, Jess P (1997) Ct in the diagnosis of abdominal wall hernias: a preliminary study. Eur Rad 7:1416–1418
59. Young J, Gilbert AI, Graham MF (2007) The use of ultrasound in the diagnosis of abdominal wall hernias. Hernia 11:347–351
60. Lee L, Mappin-Kasirer B, Liberman AS, Stein B, Charlebois P, Vassiliou M, Fried GM, Feldman LS (2012) High incidence of symptomatic incisional hernia after midline extraction in laparoscopic colon resection. Surg Endosc 26:3180–3185
61. Burger JW, van't Riet M, Jeekel J (2002) Abdominal incisions: techniques and postoperative complications. Scand J Surg 91:315–321
62. Weiland DE, Bay C, Del Sordi S (1998) Choosing the best abdominal closure by meta-analysis. Am J Surg 176:666–670
63. Gurusamy KS, Cassar Delia E, Davidson BR (2013) Peritoneal closure versus no peritoneal closure for patients undergoing non-obstetric abdominal operations. Cochrane Database Syst Rev Issue 7. Art. No.: CD010424
64. Israelsson LA (1999) Bias in clinical trials: the importance of suture technique. Eur J Surg 165:3–7
65. Nelson RL, Vedula SS (2006) Closure methods for laparotomy incisions. Cochrane Database Systc Rev Issue 1 Art. No.: CD005661
66. Jenkins TP (1976) The burst abdominal wound: a mechanical approach. Br J Surg 63:873–876
67. Israelsson LA, Jonsson T (1993) Suture length to wound length ratio and healing of midline laparotomy incisions. Br J Surg 80:1284–1286
68. Israelsson LA, Millbourn D (2012) Closing midline abdominal incisions. Langenbecks Arch Surg 397:1201–1207
69. Millbourn D, Cengiz Y, Israelsson LA (2009) Effect of stitch length on wound complications after closure of midline incisions: a randomized controlled trial. Arch Surg 144:1056–1059
70. Wissing J, van Vroonhoven TJ, Schattenkerk ME, Veen HF, Ponsen RJ, Jeekel J (1987) Fascia closure after midline laparotomy: results of a randomized trial. Br J Surg 74:738–741
71. Wang ZX, Jiang CP, Cao Y, Ding YT (2013) Systematic review and meta-analysis of triclosan-coated sutures for the prevention of surgical-site infection. Br J Surg 100:465–473
72. Diener MK, Knebel P, Kieser M, Schüler P, Schiergens TS, Atanassov V, Neudecker J, Stein E, Thielemann H, Kunz R, von Frankenberg M, Schernikau U, Bunse J, Jansen-Winkeln B, Partecke LI, Prechtl G, Pochhammer J, Bouchard R, Hodina R, Beckurts KT, Leißner L, Lemmens HP, Kallinowski F, Thomusch O, Seehofer D, Simon T, Hyhlik-Dürr A, Seiler CM, Hackert T, Reissfelder C, Hennig R, Doerr-Harim C, Klose C, Ulrich A, Büchler MW (2014) Effectiveness of triclosan-coated PDS Plus versus uncoated PDS II sutures for prevention of surgical site infection after abdominal wall closure: the randomised controlled PROUD trial. Lancet 384:142–152
73. Rasić Z, Schwarz D, Adam VN, Sever M, Lojo N, Rasić D, Matejić T (2011) Efficacy of antimicrobial triclosan-coated polyglactin 910 (Vicryl* Plus) suture for closure of the abdominal wall after colorectal surgery. Coll Antropol 35:439–443
74. Nakamura T, Kashimura N, Noji T, Suzuki O, Ambo Y, Nakamura F, Kishida A (2013) Triclosan-coated sutures reduce the incidence of wound infections and the costs after colorectal surgery: a randomized controlled trial. Surgery 153:576–583
75. Justinger C, Slotta JE, Ningel S, Graber S, Kollmar O, Schilling MK (2013) Surgical-site infection after abdominal wall closure with triclosan-impregnated polydioxanone sutures: results of a randomized clinical pathway facilitated trial. Surgery 3:589–595
76. Baracs J, Huszár O, Sajjadi SG, Horváth OP (2011) Surgical site infections after abdominal closure in colorectal surgery using triclosan-coated absorbable suture (PDS Plus) vs. uncoated sutures (PDS II): a randomized multicenter study. Surg Infect (Larchmt) 12:483–489
77. Stafford MK, Pitman MC, Nanthakumaran N, Smith JR (1998) Blunt-tipped versus sharp-tipped needles: wound morbidity. J Obstet Gynaecol 18:18–19

78. Khorgami Z, Shoar S, Laghaie B, Aminian A, Hosseini Araghi N, Soroush A (2013) Prophylactic retention sutures in midline laparotomy in high-risk patients for wound dehiscence: a randomized controlled trial. J Surg Res 180:238–243
79. Agarwal A, Hossain Z, Agarwal A, Das A, Chakraborty S, Mitra N, Gupta M, Ray U (2011) Reinforced tension line suture closure after midline laparotomy in emergency surgery. Trop Doct 41:193–196
80. Rink AD, Goldschmidt D, Dietrich J, Nagelschmidt M, Vestweber KH (2000) Negative side-effects of retention sutures for abdominal wound closure. A prospective randomised study. Eur J Surg 166:932–937
81. Mäkelä JT, Kiviniemi H, Juvonen T, Laitinen S (1995) Factors influencing wound dehiscence after midline laparotomy. Am J Surg 170:387–390
82. Matsuoka J, Gohchi A, Kamikawa Y, Sakagami K, Orita K (1995) Chopstick retention suture for the closure of abdominal wounds. J Am Coll Surg 181:471–474
83. Penninckx FM, Poelmans SV, Kerremans RP, Beckers JP (1979) Abdominal wound dehiscence in gastroenterological surgery. Ann Surg 189:345–352
84. Irvin TT, Stoddard CJ, Greaney MG, Duthie HL (1977) Abdominal wound healing: a prospective clinical study. Br Med J 2:351–352
85. Hubbard TB Jr, Rever WB Jr (1972) Retention sutures in the closure of abdominal incisions. Am J Surg 124:378–380
86. Rahbari NN, Knebel P, Diener MK, Seidlmayer C, Ridwelski K, Stoltzing H, Seiler CM (2009) Current practice of abdominal wall closure in elective surgery—is there any consensus? BMC Surgery 9:8
87. Bouvier A, Rat P, Drissi-Chbihi F, Bonnetain F, Lacaine F, Mariette C, Ortega-Deballon P (2014) Abdominal binders after laparotomy: review of the literature and French survey of policies. Hernia 18:501–506
88. Pommergaard HC, Burcharth J, Danielsen A, Angenete E, Haglind E, Rosenberg J (2013) No consensus on restrictions on physical activity to prevent incisional hernias after surgery. Hernia 18:495–500
89. Kosins AM, Scholz T, Cetinkaya M, Evans GR (2013) Evidence-based value of subcutaneous surgical wound drainage: the largest systematic review and meta-analysis. Plast Reconstr Surg 132:443–450
90. Nakayama H, Takayama T, Okubo T, Higaki T, Midorikawa Y, Moriguchi M, Aramaki O, Yamazaki S (2014) Subcutaneous drainage to prevent wound infection in liver resection: a randomized controlled trial. J Hepatobiliary Pancreat Sci 21:509–517
91. Numata M, Godai T, Shirai J, Watanabe K, Inagaki D, Hasegawa S, Sato T, Oshima T, Fujii S, Kunisaki C, Yukawa N, Rino Y, Taguri M, Morita S, Masuda M (2014) A prospective randomized controlled trial of subcutaneous passive drainage for the prevention of superficial surgical site infections in open and laparoscopic colorectal surgery. Int J Colorectal Dis 29:353–358
92. Kaya E, Paksoy E, Ozturk E, Sigirli D, Bilgel H (2010) Subcutaneous closed-suction drainage does not affect surgical site infection rate following elective abdominal operations: a prospective randomized clinical trial. Acta Chir Belg 110:457–462
93. Baier PK, Gluck NC, Baumgartner U, Adam U, Fischer A, Hopt UT (2010) Subcutaneous Redon drains do not reduce the incidence of surgical site infections after laparotomy. A randomized controlled trial on 200 patients. Int J Colorectal Dis 25:639–643
94. Chowdri NA, Qadri SA, Parray FQ, Gagloo MA (2007) Role of subcutaneous drains in obese patients undergoing elective cholecystectomy: a cohort study. Int J Surg 5:404–407
95. Panici PB, Zullo MA, Casalino B, Angioli R, Muzii L (2003) Subcutaneous drainage versus no drainage after minilaparotomy in gynecologic benign conditions: a randomized study. Am J Obstet Gynecol 188:71–75
96. Gallup DC, Gallup DG, Nolan TE, Smith RP, Messing MF, Kline KL (1996) Use of a subcutaneous closed drainage system and antibiotics in obese gynecologic patients. Am J Obstet Gynecol 175:358–361
97. Loong RL, Rogers MS, Chang AM (1988) A controlled trial on wound drainage in caesarean section. Aust N Z J Obstet Gynaecol 28:266–269
98. Shaffer D, Benotti PN, Bothe A Jr, Jenkins RL, Blackburn GL (1987) A prospective, randomized trial of abdominal wound drainage in gastric bypass surgery. Ann Surg 206:134–137
99. Ali J, Serrette C, Khan TA (1983) The effect of abdominal binders on postoperative pulmonary function. Infect in Surg 2:875–881
100. Fagevik Olsén M, Josefson K, Wiklund M (2009) Evaluation of abdominal binder after major upper gastrointestinal surgery. Adv in Physiother 11:104–110
101. Larson CM, Ratzer ER, Davis-Merritt D, Clark JR (2009) The effect of abdominal binders on postoperative pulmonary function. Am Surg 75:169–171
102. Cheifetz O, Lucy SD, Overend TJ, Crowe J (2010) The effect of abdominal support on functional outcomes in patients following major abdominal surgery: a randomized controlled trial. Physiother Can 62:242–253
103. Clay L, Gunnarsson U, Franklin KA, Strigård K (2014) Effect of an elastic girdle on lung function, intra-abdominal pressure, and pain after midline laparotomy: a randomized controlled trial. Int J Colorectal Dis 29:715–721
104. Timmermans L, de Goede B, Eker HH, van Kempen BJ, Jeekel J, Lange JF (2013) Meta-analysis of primary mesh augmentation as prophylactic measure to prevent incisional hernia. Dig Surg 30:401–409
105. Abo-Ryia MH, El-Khadrawy OH, Abd-Allah HS (2013) Prophylactic preperitoneal mesh placement in open bariatric surgery: a guard against incisional hernia development. Obes Surg 23:1571–1574
106. Caro-Tarrago A, Olona Casas C, Jimenez Salido A, Duque Guilera E, Moreno Fernandez F, Vicente Guillen V (2014) Prevention of incisional hernia in midline laparotomy with an onlay mesh: a randomized clinical trial. World J Surg 38:2223–2230
107. Gutiérrez de la Pena C, Medina Achirica C, Dominguez-Adame E, Medina Diez J (2003) Primary closure of laparotomies with high risk of incisional hernia using prosthetic material: analysis of usefulness. Hernia 7:134–136
108. Strzelczyk JM, Szymanski D, Nowicki ME, Wilczynski W, Gaszynski T, Czupryniak L (2006) Randomized clinical trial of postoperative hernia prophylaxis in open bariatric surgery. Br J Surg 93:1347–1350
109. El-Khadrawy OH, Moussa G, Mansour O, Hashish MS (2009) Prophylactic prosthetic reinforcement of midline abdominal incisions in high-risk patients. Hernia 13:267–274
110. Bevis PM, Windhaber RA, Lear PA, Poskitt KR, Earnshaw JJ, Mitchell DC (2010) Randomized clinical trial of mesh versus sutured wound closure after open abdominal aortic aneurysm surgery. Br J Surg 97:1497–1502
111. Pans A, Elen P, Desaive C, Andre C (1998) Long-term results of polyglactin mesh for the prevention of incisional hernias in obese patients. World J Surg 22:479–483
112. Llaguna OH, Avgerinos DV, Nagda P, Elfant D, Leitman IM, Goodman E (2011) Does prophylactic biologic mesh placement protect against the development of incisional hernia in high-risk patients? World J Surg 35:1651–1655

113. Armañanzas L, Ruiz-Tovar J, Arroyo A, García-Peche P, Armañanzas E, Diez M, Galindo I, Calpena R (2014) Prophylactic mesh vs suture in the closure of the umbilical trocar site after laparoscopic cholecystectomy in high-risk patients for incisional hernia. A randomized clinical trial. J Am Coll Surg 218:960–968
114. Bhoyrul S, Payne J, Steffes B, Swanstrom L, Way LW (2000) A randomized prospective study of radially expanding trocars in laparoscopic surgery. J Gastrointest Surg 4:392–397
115. Bonjer HJ, Hazebroek EJ, Kazemier G, Giuffrida MC, Meijer WS, Lange JF (1997) Open versus closed establishment of pneumoperitoneum in laparoscopic surgery. Br J Surg 84:599–602
116. Bowrey DJ, Blom D, Crookes PF, Bremner CG, Johansson JL, Lord RV, Hagen JA, DeMeester SR, DeMeester TR, Peters JH (2001) Risk factors and the prevalence of trocar site herniation after laparoscopic fundoplication. Surg Endosc 15:663–666
117. Bunting DM (2010) Port-site hernia following laparoscopic cholecystectomy. JSLS 14:490–497
118. Chiu CC, Lee WJ, Wang W, Wei PL, Huang MT (2006) Prevention of trocar-wound hernia in laparoscopic bariatric operations. Obes Surg 16:913–918
119. Clark LH, Soliman PT, Odetto D, Munsell MF, Schmeler KM, Fleming N, Westin SN, Nick AM, Ramirez PT (2013) Incidence of trocar site herniation following robotic gynecologic surgery. Gynecol Oncol 131:400–403
120. Comajuncosas J, Hermoso J, Gris P, Jimeno J, Orbeal R, Vallverdú H, López Negre JL, Urgellés J, Estalella L, Parés D (2014) Risk factors for umbilical trocar site incisional hernia in laparoscopic cholecystectomy: a prospective 3-year follow-up study. Am J Surg 207:1–6
121. Delmonaco P, Cirocchi R, La Mura F, Morelli U, Migliaccio C, Napolitano V, Trastulli S, Farinella E, Giuliani D, Desol A, Milani D, Di Patrici MS, Spizzirri A, Bravetti M, Sciannameo V, Avenia N, Sciannameo F (2011) Trocarsite hernia after laparoscopic colectomy: a case report and literature review. ISRN Surgery 2011:725601
122. Eid GM, Collins J (2005) Application of a trocar wound closure system designed for laparoscopic procedures in morbidly obese patients. Obes Surg 15:871–873
123. Erdas E, Dazzi C, Secchi F, Aresu S, Pitzalis A, Barbarossa M, Garau A, Murgia A, Contu P, Licheri S, Pomata M, Farina G (2012) Incidence and risk factors for trocar site hernia following laparoscopic cholecystectomy: a long-term follow-up study. Hernia 16:431–437
124. Feste JR, Bojahr B, Turner DJ (2000) Randomized trial comparing a radially expandable needle system with cutting trocars. JSLS 4:11–15
125. Helgstrand F, Rosenberg J, Kehlet H, Bisgaard T (2011) Low risk of trocar site hernia repair 12 years after primary laparoscopic surgery. Surg Endosc 25:3678–3682
126. Holzinger F, Klaiber C (2002) Trocar site hernias. A rare but potentially dangerous complication of laparoscopic surgery. Chirurg 73:899–904
127. Hussain A, Mahmood H, Singhal T, Balakrishnan S, Nicholls J, El-Hasani S (2009) Long-term study of port-site incisional hernia after laparoscopic procedures. JSLS 13:346–349
128. Johnson WH, Fecher AM, McMahon RL, Grant JP, Pryor AD (2006) VersaStep trocar hernia rate in unclosed fascial defects in bariatric patients. Surg Endosc 20:1584–1586
129. Kadar N, Reich H, Liu CY, Manko GF, Gimpelson R (1993) Incisional hernias after major laparoscopic gynecologic procedures. Am J Obstet Gynecol 168:1493–1495
130. Leibl BJ, Schmedt CG, Schwarz J, Kraft K, Bittner R (1999) Laparoscopic surgery complications associated with trocar tip design: review of literature and own results. J Laparoendosc Adv Surg Tech A 9:135–140
131. Mayol J, Garcia-Aguilar J, Ortiz-Oshiro E, De-Diego Carmona JA, Fernandez-Represa JA (1997) Risks of the minimal access approach for laparoscopic surgery: multivariate analysis of morbidity related to umbilical trocar insertion. World J Surg 21:529–533
132. Moran DC, Kavanagh DO, Sahebally S, Neary PC (2012) Incidence of early symptomatic port-site hernia: a case series from a department where laparoscopy is the preferred surgical approach. Ir J Med Sci 181:463–466
133. Moreno-Sanz C, Picazo-Yeste JS, Manzanera-Díaz M, Herrero-Bogajo ML, Cortina-Oliva J, Tadeo-Ruiz G (2008) Prevention of trocar site hernias: description of the safe port plug technique and preliminary results. Surg Innov 15:100–104
134. Sánchez-Pernaute A, Pérez-Aguirre E, García Botella A, Rodríguez L, Antona EM, Cabeza J, Valladolid DJ, Rubio MA, Delgado I, Torres A (2008) Prophylactic closure of trocar orifices with an intraperitoneal mesh (ventralex) in laparoscopic bariatric surgery. Obes Surg 18:1489–1491
135. Schmedt CG, Leibl BJ, Däubler P, Bittner R (2001) Access-related complications—an analysis of 6023 consecutive laparoscopic hernia repairs. Min Invas Ther & Allied Technol 10:23–30
136. Tonouchi H, Ohmori Y, Kobayashi M, Kusunoki M (2004) Trocar site hernia. Arch Surg 139:1248–1256
137. Uslu HY, Erkek AB, Cakmak A, Kepenekci I, Sozener U, Kocaay FA, Turkcapar AG, Kuterdem E (2007) Trocar site hernia after laparoscopic cholecystectomy. J Laparoendosc Adv Surg Tech A 17:600–603
138. Garg P, Thakur JD, Garg M, Menon GR (2012) Single-incision laparoscopic cholecystectomy vs conventional laparoscopic cholecystectomy: a meta-analysis of randomized controlled trials. J Gastrointest Surg 16:1618–1628
139. Trastulli S, Cirocchi R, Desiderio J, Guarino S, Santoro A, Parisi A, Noya G, Boselli C (2013) Systematic review and meta-analysis of randomized clinical trials comparing single-incision versus conventional laparoscopic cholecystectomy. Br J Surg 100:191–208
140. Milas M, Devetija S, Trkulja V (2014) Single incision versus standard multiport laparoscopic cholecystectomy: up-dated systematic review and meta-analysis of randomized trials. Surgeon 12:271–289
141. Sackett DL, Rosenberg WM, Gray JA, Haynes RB, Richardson WS (1996) Evidence based medicine: what it is and what it isn't. BMJ 312:71–72
142. van Ramshorst GH, Nieuwenhuizen J, Hop WC, Arends P, Boom J, Jeekel J, Lange JF (2010) Abdominal wound dehiscence in adults: development and validation of a risk model. World J Surg 34:20–27
143. van Ramshorst GH, Klop B, Hop WCJ, Israelsson LA, Lange JF (2013) Closure of midline laparotomies by means of small stitches: practical aspects of a new technique. Surg Technol Int 23:34–38
144. Muysoms F, Campanelli G, Champault GG, deBeaux AC, Dietz UA, Jeekel J, Klinge U, Köckerling F, Mandala V, Montgomery A, Morales Conde S, Puppe F, Simmermacher RKJ, Śmietański M, Miserez M (2012) EuraHS: the development of an international online platform for registration and outcome measurement of ventral abdominal wall hernia repair. Hernia 16:239–250