

The role of prophylactic mesh placement to prevent incisional hernia in laparotomy. Is it time to change practice?

Michael Sugrue^{1,2}, Alison Johnston¹, Saqib Zeeshan¹, Paula Loughlin^{2,3},
Magda Bucholc², Angus Watson^{2,4}

¹Department of Surgery, Letterkenny University Hospital and Donegal Clinical Research Academy, Ireland

²EU INTERREG Centre for Personalised Medicine, Intelligent Systems Research Centre, School of Computing, Engineering, and Intelligent Systems, Ulster University, Magee Campus, Derry-Londonderry, Northern Ireland, United Kingdom

³Department of Surgery, Altnagelvin Hospital, Derry-Londonderry, Northern Ireland, United Kingdom

⁴Raighmore Hospital, Inverness, Scotland, United Kingdom

Abstract

Background: Incisional hernia (IH) occurs in approximately 25% of laparotomies. Prophylactic mesh placement (PMP) may significantly reduce IH but is not widely used. This paper will review the evidence relating to the role of PMP in laparotomy and its ability to effectively and safely have an impact on hernia reduction.

Methods: An ethically approved review of all published English articles relating to IH prevention following laparotomy was undertaken at Letterkenny University Hospital by searching PubMed, Scopus, and electronic databases over a 20-year period from January 1999 to March 2019. The search terms “incisional hernia”, “laparotomy”, “mesh placement”, “reoperation”, “readmitted”, and “rates” were used in combination.

Results: The literature identified 17 publications, of which 14 were randomised, controlled trials and three were prospective cohort studies from 22 countries. Bariatric surgery accounted for eight of the 17 studies. Onlay mesh placement was used in five studies. Preperitoneal, retrorectus, intra-peritoneal, combinations of and sublay were used in 4, 3, 2, 2, and 1 studies, respectively. In two studies both sublay and onlay were performed. A total of 2777 patients were reported. One study had two publications with different lengths of follow-up.

Conclusions: Currently surgeons need to consider changing practice to firstly ensure they practice optimum laparotomy closure technique and potentially use PMP. If not using PMP they need to question why, because PMP will more than halve the IH rate, especially in higher risk patients undergoing laparotomy.

Key words: incisional hernia, laparotomy, emergency surgery, prophylactic mesh placement, mesh.

Anaesthesiol Intensive Ther 2019; 51, 3

Received: 15.04.2019, accepted: 14.06.2019

CORRESPONDING AUTHOR:

Michael Sugrue, Letterkenny University Hospital,
Donegal, Ireland, e-mail: michael.sugrue@hse.ie

Surgeons for centuries have salvaged patients dying with abdominal catastrophes, ranging from simple appendicitis to advanced peritonitis. Survival dominated former surgical goals, but with advances in resuscitations, sepsis source control, and surgical techniques, there is now more time to focus on quality outcomes with reduction in morbidity, re-admission, and reoperation [1, 2]. Bundles have been used to improve perioperative care and have been highly effective in reducing surgical site infection (SSI), including deep organ space infection [3].

In conjunction with clinical improvements, powerful data registries are alerting us to the frequency and problems posed by incisional hernia [4]. Over

one million laparotomies are performed annually in the USA alone. Increasing use of metrics allows more transparent identification of both early and late complications. Surgical site occurrence (SSO) occurs on average in 15% of those undergoing laparotomy (range 5–45%), with significant cost and morbidity [5].

There have been many paradigm shifts in hernia prevention and repair since Usher's first use of Marlex to repair an incisional hernia (IH) in 1958 [6]. In general it is now standard of care to use mesh in both umbilical and incisional hernia repair [7]. This is not entirely uniform, however, and the use of mesh for umbilical hernia repair is debated, possibly

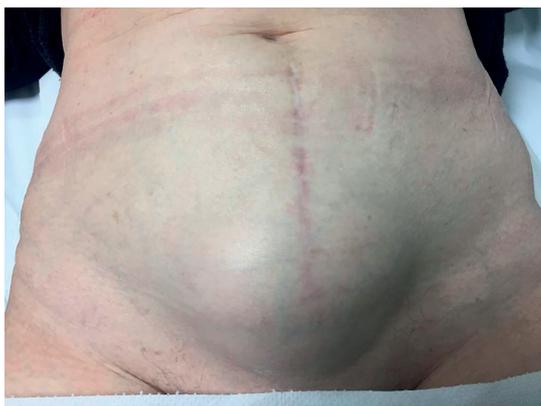


FIGURE 1. A large lower abdominal incisional hernia one year post laparotomy

related to the concern that mesh may increase the risk of surgical site infections [8].

Surgeons have been slow to recognise the burden of incisional hernia following laparotomy [9, 10]. The incidence of incisional hernias is approximately 15% at one year, rising to 25% at three years (range 10–50%) [11]. Prophylactic mesh placement (PMP) has been shown to at least halve the problem [12, 13].

Mesh has been placed in wounds for centuries with variable results [14]. The concept of mesh insertion and potential mesh related complications has been a barrier to their insertion. Contaminated wounds during index laparotomy or subsequent SSI development are a source of great anxiety to surgeons [15].

PMP involves mesh implantation, usually in the onlay or underlay position. Underlay can either be in retrorectus positions, preperitoneal or intraperitoneally (IPOM) at the time of initial abdominal fascial closure. Recent studies suggest that prevention of IH via PMP may be the solution to this hernia epidemic [16, 17].

This paper will review the evidence relating to the role of prophylactic mesh placement at laparotomy and its ability to effectively and safely impact on hernia reduction.

METHODS

An ethically approved review of all published English articles relating to IH prevention following laparotomy was undertaken at Letterkenny University Hospital searching PubMed, Scopus, and electronic databases over a 20-year period from January 1999 to March 2019. The search terms “incisional hernia”, “laparotomy”, “mesh placement”, “reoperation”, “readmitted” and “rates” were used in combination with Boolean operators AND or OR. Studies were included in this review if they were either randomized controlled trials (RCTs) or prospective cohort studies involving analysis of incisional hernia,

following use of mesh prophylactically placed either in laparotomy or open abdomen closure. Studies relating to stomal herniation, paediatric, and those in which data was inadequate for interpretation were not included.

Incisional hernia was clinically defined as any visible and/or palpable “blowout” within a distance of 3 cm from the midline abdominal scar and an example is shown in Figure 1. The ultrasonic criteria of incisional hernia were a visible gap within the abdominal wall and/or “tissue moving through the abdominal wall by Valsalva manoeuvre” and/or a detectable “blowout”. For the diagnosis of incisional hernia, either clinical criteria, or ultrasound or CT criteria or both had to be fulfilled. The study did not distinguish between single and multiple incisional hernias.

RESULTS

The literature identified 17 publications, of which 14 were RCTs and 3 prospective cohort studies from 22 countries. Bariatric surgery accounted for 8 of the 17 studies. Onlay mesh placement was used in 5 studies. Preperitoneal, retrorectus, intraperitoneal, combinations of and sublay were used in 4, 3, 2, 2 and 1 studies respectively. In two studies both sublay and onlay were performed (Table 1), a total of 2777 patients were reported. One study had two publications with different lengths of follow up.

WHICH PATIENTS SHOULD BE TREATED?

Many issues come into play before answering this question; what is the patient’s physiology, operative wound classification, cost and type of mesh to be used. Before considering PMP we have to ensure appropriate decision making and surgical technique are optimized at the first operation.

The choice of primary incision is important as it has been suggested that lateral paramedian incisions have a lower incidence than with midline incisions [18, 19]. Some studies have however failed to detect any difference [20, 21]. Paramedian incisions are more difficult to perform than midline incision. Muscle splitting incisions such as the Lanz, gridiron incision and the Pfannenstiel incision have a slightly lower rate of wound complications. These incisions however provide reduced access to the abdomen and increased numbness [22]. A number of key surgical techniques proven to reduce incisional hernia without the use of mesh are shown in Table 2. These should be implemented as a routine.

Nearly all published trials have shown benefit when PMP is used in higher risk patient as shown in Table 3 [7, 23–25]. Patients undergoing midline laparotomies are at the greatest risk, with rates in general approaching 20% at 3 years although this

TABLE 1. Randomized controlled trials and prospective studies of prophylactic mesh placement during laparotomy

Study	Year	Location	Patients	Position	Study No
Pans [33]	1998	Belgium	Bariatric	IPOM	288
Strzelczyk [32]	2002	Poland	Bariatric	Onlay	60
Gutierrez de la Pena [51]	2003	Spain	Cancer	Onlay	88
Strzelczyk [52]	2006	Poland	Bariatric	Retrorectus	72
El-Khadrawy [53]	2009	Egypt	Bariatric	Preperitoneal	40
Bevis [54]	2010	UK	AAA	Sublay	80
Llaguna [55]	2011	USA	Bariatric	Preperitoneal	106
Abo-Ryia [56]	2013	Egypt	Bariatric	Preperitoneal	64
Curro [57]	2012	Italy	Bariatric	Retrorectus	95
Caro-Tarrago [58]	2014	Spain	Cancer	Onlay	160
Sarr [59]	2014	USA	Bariatric	Preperitoneal	380
Bali [60]	2015	Greece	AAA	Onlay	40
Timmermans [36]	2015	Netherlands	AAA	Onlay-sublay	480
Muysoms [61]	2016	Belgium	AAA	Retrorectus	114
Jairam [13]	2017	Austria Germany Holland	Mixed	Onlay-sublay	480
Caro-Tarrago [62]	2019	Spain	Cancer	Onlay	80
Kohler [37]	2019	Switzerland	Cancer	IPOM	150

TABLE 2. Surgical technique as prevention of incisional hernia

Measuring wound length
Documenting the suture to wound length
Suture to wound length ratio 4 : 1
Use of self-locking sutures
Closure of the fascia in one layer
Low tension
Small stitches
Using a monofilament suture

TABLE 3. Patients at great risk of incisional hernia

Obese, BMI > 27 kg m ⁻²
Elderly
Aortic or bariatric surgery
History of hernias
Carcinoma
Chronic obstructive pulmonary disease
Emergency surgery
Previous laparotomy

is higher in select groups. Those undergoing aortic surgery are at increased risk [26].

Fischer *et al.* studied the incidence of incisional hernia post laparotomy and associated risk factors, enabling them to create a composite risk score [27]. In their cohort of 12,373 patients there was a wide variation in the incidence of IH from 0.5 to 20.6%, in the low and extreme risk groups, respectively. A similar study by Basta *et al.* risk stratified patients following bariatric surgery and were able to accurately predict the risk [28]. Both studies report increased healthcare costs associated with their higher risk groups. The use of a risk stratification model would allow healthcare providers to be more targeted when considering the use of a prophylactic mesh.

Goodenough and colleagues, in a prospective study using a scoring model to predict IH after abdominal surgery, found three preoperative and intraoperative findings independently associated with IH formation [25]. These were surgical approach (open laparotomy vs. hand-assisted laparoscopy vs.

laparoscopy), COPD, and BMI > 25 kg m⁻². In their study the lowest risk patients developed an IH in 5.5% compared to over 50% in the highest risk group. While their score is straightforward to calculate, practical, and can be estimated preoperatively to determine a patient’s risk it is not widely used.

Although the data are favourable and consistent for prophylactic mesh augmentation, the Guideline 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 [7].

We should not forget preoperative risk reduction strategies starting with appropriate patient selection, weight loss programs, nutritional optimization, cessation of smoking and pre-habilitation, to include pre-operative chest physio, are to be commended. In the emergency situation, and in those undergoing major abdominal wall reconstructions, factors to reduce intra-abdominal pressure are important [29, 30].



FIGURE 2. Prophylactic TIGR onlay mesh fixed by tacking on right side and suturing on left

WHAT TYPE OF MESH

The choice of mesh can be simplified into 3 main categories: synthetic, biosynthetic and biological. In addition the mesh may be absorbable or non-absorbable, with or without a hybrid component. Furthermore meshes can vary in weight, pore size and resistant to colonization [31]. This classification can be further complicated by additive agents ranging from biospheres to antiseptic impregnation. Prolene based meshes have been used since 2002 when Strzelczyk found polypropylene mesh highly effective in preventing IH with 0% IH in the mesh group compared to 21% in the non mesh group at 6 months follow-up [32]. Pans however, in one of the first studies almost 21 years ago, reported that absorbable PMP had no effect on reducing IH with 22.9% IH rate in the mesh versus 28.5% in the no mesh group. Pan used intraperitoneal polyglactin mesh which was not fixed [33].

In a recent systematic review Muysoms suggested there is no overwhelming evidence on the effectiveness of prophylactic non-permanent absorbable biological or biosynthetic mesh for the closure of laparotomies. There is no evidence that, in this setting, a non-permanent absorbable biological or biosynthetic mesh would be preferred to synthetic non-absorbable mesh, both in clean or clean-contaminated surgery [34]. Furthermore, the on-going PREBIOUS trial is attempting to determine the efficacy of bioabsorbable meshes [35]. The potential attraction of bioabsorbable meshes is that they behave like synthetics with good tensile strength but eventually reabsorb which could lead to less chronic pain and a possible decreased infection risk. There is increasing interest in hybrid meshes but no real data to support their use.

WHICH POSITION SHOULD THE MESH BE PLACED?

Mesh can be placed either as an onlay, retro-rectus, sublay in the preperitoneal plane or intraperitoneally (IPOM). An example of an onlay mesh placement is shown in Figure 2. Potentially a combination of locations could be used.

Kohler in a recent randomized trial found prophylactic intraperitoneal mesh implantation significantly reduced the incidence of incisional hernia 3 years after laparotomy compared with standard abdominal closure in a high-risk population with IH occurring in 7.2% vs. 18.5% in the non-mesh group [37]. At present there is little evidence on the long-term results of the prophylactic use of mesh, but the protective effect of the use of an onlay mesh in abdominal wall closure is maintained for at least up to 5 years after surgery.

Jairam *et al.* in the PRIMA trial, a randomised controlled trial from 3 countries, found onlay mesh reinforcement significantly reduced the incidence of incisional hernia after midline laparotomy in patients at high risk for incisional hernia (i.e. those with abdominal aortic aneurysm or a BMI ≥ 27 kg m⁻²). Sublay mesh reinforcement did not have a significant effect on the incidence of incisional hernia compared with primary suture [13].

WHAT ABOUT IN CONTAMINATION?

To-date there have been several studies demonstrating the efficacy of using macroporous polypropylene mesh in both class 2 and class 3 wounds [38, 39].

There is a growing body of literature on the efficacy of bioabsorbable meshes for a similar purpose as well as on-going clinical studies such as the PREBIOUS trial [35, 40]. While Choi *et al.* in a study of the adverse effect of mesh in clean and clean contaminated ventral hernia repair expressed caution about its use; their study is somewhat dated and without information on the type of mesh or the primary surgery [41]. They found postoperative occurrences were significantly greater in clean-contaminated and contaminated cases using mesh when compared with clean cases, with odds ratios of 3.56 (3.25–3.89) and 5.05 (1.78–12.41) respectively. There was a significantly increased risk of superficial SSI (2.53), deep SSI (3.09) and organ/space SSI (6.16), wound disruption (4.41), pneumonia (4.43), and sepsis (4.90) for clean-contaminated cases where mesh was used.

Argudo *et al.* in a retrospective study found that the use of a partially absorbable, lightweight large pore prophylactic mesh in the closure of emergency midline laparotomies is feasible for the prevention of incisional hernia without adding a substantial rate of morbidity to the procedure, even if high contamination or infections are present suggesting that accel-

lular dermal matrix may be an acceptable option for repair of clean contaminated or contaminated defects, with a 23% 2-year rate of hernia recurrence in reinforced acellular dermal matrix repairs [42].

Itani *et al.*'s prospective, multicenter, single-arm study of open VIH repairs of contaminated abdominal defects with a non-cross-linked, porcine, acellular dermal matrix found an early recurrence rate of 7.1% in clean-contaminated defects at approximately 11 months' follow-up. They found no unanticipated adverse events occurred, and no tissue matrix required complete excision. There were however 22 hernia (28%) recurrences by month 24. There was no correlation between infection-related events and hernia recurrence [43]. In other areas such as emergency stoma creation Lykke *et al.* found that the insertion of absorbable mesh, even in the presence of contamination, was not associated with increased complications [44]. It appears that permanent synthetic or biosynthetic mesh can now be used in clean-contaminated and contaminated fields.

WHAT ABOUT THE OPEN ABDOMEN CLOSURE?

There is increasing evidence that final closure of the open abdomen will benefit by PMP. The evidence however is still limited and this would depend on the degree of contamination. When placement of mesh is considered reasonably safe it should be macro porous.

Studies have shown that VAC-IPOM in patients with OA treatments decrease re-operations, duration of hospital and ICU stay, and the incidence of incisional hernia, when compared with VAWCM, which represents the current standard of care [45, 46].

COSTS

According to recent estimates healthcare costs related to incisional hernias vary from \$3,875 to \$98,424 per patient and the overall cost approaches 3 billion dollars in the USA alone [47]. More than 340,000 ventral hernia surgical procedures are performed in the United States each year, accounting for at least \$3.2 billion in health care. It has been calculated that in the United States, each 1% reduction in hernia recurrence would result in a saving of at least \$32 million in procedural costs. The use of mesh could reduce the incidence of IH from 25–30% to 10% and therefore is cost-effective due to the number needed to treat obtained: one IH was prevented for every 5 prophylactic meshes that were used.

The mean total cost for an IH in France in 2011 was estimated to be 6451€, ranging from 4731€ for unemployed patients to 10,107€ for employed patients whose indirect costs (5376€) were slightly higher than the direct costs. Reducing the incidence of IH after abdominal surgery by 5% following implementation of the European Hernia Society

Guidelines on closure of abdominal wall incisions, or maybe even by use of prophylactic mesh augmentation in high risk patients would result in a national cost savings of 4 million euros [7].

PROBLEMS WITH MESH INSERTION

Mesh infection, explantation, migration and fistulation are uncommon. Seroma rates are slightly increased with onlay and increased pain may be seen especially in the early post-operative period with the retrorectus approach. When an SSI occurs in the presence of mesh it may take longer to heal.

During analysis significantly ($P = 0.002$) more seromas were detected after OMA ($n = 34, 18.1\%$) compared with primary suture ($n = 5, 4.7\%$) and sublay mesh augmentation ($n = 13, 7.0\%$). No differences were seen in surgical site infection, hematoma, reintervention, or readmission [35].

At 6 weeks, significantly more patients in the mesh group reported postoperative pain compared with patients in the control group (34 of 52 [65.4%] vs. 26 of 59 [44.1%]; effect size, 21.3%; 95% CI: 4–41%; $P = 0.04$). Pain intensity was higher in the mesh group compared with the control group at 6 weeks (mean VAS score, 1.61 vs. 0.83; VAS score difference, 0.78; 95% CI: 0.10–1.46%; $P = 0.02$). At 1 and 3 years after surgery, no difference in pain perception was observed between the groups). No difference in surgical site infections was observed, but time to complete wound healing of surgical site infection was significantly longer in patients with mesh implantation (median [interquartile range], 8 [6–24] weeks compared with 5 [1–9] weeks; $P = 0.03$). Trunk extension was significantly decreased after mesh implantation compared with the control group. A trend towards increased chronic pain after mesh implantation has been reported in the past [37].

CURRENT LIMITATIONS

There is no gold standard for the diagnosis of ventral hernias. Clinical examination is potentially subject to under diagnosis, can vary widely between clinicians, and is affected by patient factors such as obesity. Radiographic imaging has been shown to have significant inter-observer variability. Even patient-reported results are inaccurate, with up to one-third of patients unaware that they have a VIH. It remains to be seen whether in fact patients with incisional hernia are best observed or subjected to surgery, and this will be answered by the AWARE study [48]. The providers of surgical and critical care have all seen the sequelae of strangulated incisional hernia and realise that we need to re-think our approach. We may have overlooked some basic anatomical factors relating to the linea alba. Moschowitz in 1914 identified the vascular lacunae theory

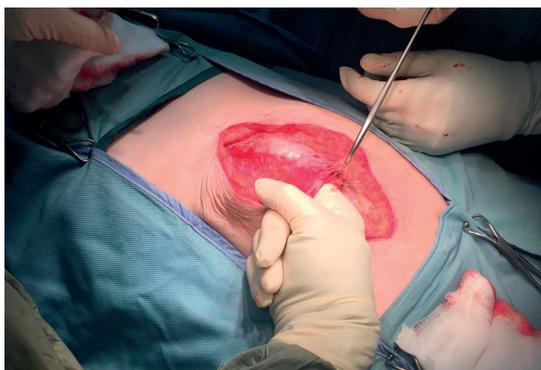


FIGURE 3. New incisional hernia below site of previous prophylactic mesh placement in a patient with multiple previous lower midline incisions

with perforation of the linea in significant numbers [49]. Sugrue described the concept of the fenestrated linea alba. In a prospective study of 146 patients, 74% male, mean body mass 84 ± 16 kg, mean age 48.6 ± 12.0 years, were studied. Ninety-four (64%) had a single defect, mean size 17.5 ± 8.3 mm (range 3–44 mm). Thirty-three (22%) patients had two defects, the mean size of the second defect 13.1 mm (range 1–22 mm) at a mean distance of 5.7 mm (range 1–30 mm). Fifteen (10%) had three defects, the mean size of the third defect 11 mm (range 1–20 mm) at a mean distance of 5.7 mm (range 1–30 mm). Four (3%) patients had four defects. All defects were cephalad. The linea alba should be exposed for 3 cm in a cephalad direction at umbilical hernia repair to identify and fix these defects. It may be one of the reasons that PMP reduces IH rates [50].

As can be seen in Figure 3 incisional hernia may develop down the whole length of a previous incision. In Kohler's recent publication there was increased early postoperative pain and prolonged wound healing of surgical site infection in those having mesh. While the pain difference in those who received mesh was confined to the early post-operative period long term trunk extension was reduced in those receiving a mesh [37].

CONCLUSIONS

This original review has identified significant evidence to support PMP in terms of both the short and long term benefit with halving the incisional hernia rate. Both permanent and biosynthetic offer different profiles and further prospective RCTs will help identify the most appropriate locations and type of mesh placement. Currently surgeons need to consider why they are not going to place a prophylactic mesh in a higher risk patient at laparotomy.

ACKNOWLEDGEMENTS

1. Financial support and sponsorship: EU INTERREG funding for Centre for Personalised Medicine.

2. Conflict of interest: Michael Sugrue served as a consultant and speaker to Smith and Nephew, Acelity and Novus Scientific. The rest of authors declare no conflict of interest.

REFERENCES

- Aggarwal G, Peden CJ, Mohammed MA, et al. Evaluation of the collaborative use of an evidence-based care bundle in emergency laparotomy. *JAMA Surg* 2019; e190145. doi: 10.1001/jamasurg.2019.0145 [Epub ahead of print].
- To KB, Kamdar NS, Patil P, et al.; Michigan Surgical Quality Collaborative (MSQC) Emergency General Surgery Study Group and the MSQC Research Advisory Group. Acute Care Surgery Model and Outcomes in Emergency General Surgery. *J Am Coll Surg* 2019; 228: 21–28. doi: 10.1016/j.jamcollsurg.2018.07.664.
- Weiser MR, Gonen M, Usiak S, et al. Effectiveness of a multidisciplinary patient care bundle for reducing surgical-site infections. *Br J Surg* 2018; 105: 1680–1687. doi: 10.1002/bjs.10896.
- Köckerling F. Onlay technique in incisional hernia repair – a systematic review. *Front Surg* 2018; 5: 71. doi: 10.3389/fsurg.2018.00071.
- Fischer JP, Basta MN, Krishnan NM, Wink JD, Kovach SJ. A cost-utility assessment of mesh selection in clean-contaminated ventral hernia repair. *Plast Reconstr Surg* 2016; 137: 647–659. doi: 10.1097/01.prs.0000475775.44891.56.
- Usher FC, Ochsner J, Tuttle JL. Use of Marlex mesh in the repair of incisional hernias. *Am Surg* 1958; 24: 969–974.
- Muysoms FE, Antoniou SA, Bury K, et al. European Hernia Society guidelines on the closure of abdominal wall incisions. *Hernia* 2015; 19: 1–24. doi: 10.1007/s10029-014-1342-5.
- Appleby PW, Martin TA, Hope WW. Umbilical hernia repair: overview of approaches and review of literature. *Surg Clin* 2018; 98: 561–576. doi: 10.1016/j.suc.2018.02.001.
- Fischer JP, Harris HW, López-Cano M, Hope WW. Hernia prevention: practice patterns and surgeons' attitudes about abdominal wall closure and the use of prophylactic mesh. *Hernia* 2019; 23: 329–334. doi: 10.1007/s10029-019-01894-z.
- Tolstrup MB, Watt SK, Gögenur I. Reduced rate of dehiscence after implementation of a standardized fascial closure technique in patients undergoing emergency laparotomy. *Ann Surg* 2017; 265: 821–826. doi: 10.1097/SLA.0000000000001762.
- Fink C, Baumann P, Wentz MN, et al. Incisional hernia rate 3 years after midline laparotomy. *Br J Surg* 2014; 101: 51–54. doi: 10.1002/bjs.9560.
- Borab ZM, Shakir S, Lanni MA, et al. Does prophylactic mesh placement in elective, midline laparotomy reduce the incidence of incisional hernia? A systematic review and meta-analysis. *Surgery* 2017; 161: 1149–1163. doi: 10.1016/j.surg.2016.09.036.
- Jairam AP, Timmermans L, Eker HH, et al. Prevention of incisional hernia with prophylactic onlay and sublay mesh reinforcement versus primary suture only in midline laparotomies (PRIMA): 2-year follow-up of a multicentre, double-blind, randomised controlled trial. *Lancet* 2017; 390: 567–576. doi: 10.1016/S0140-6736(17)31332-6.
- Sanders DL, Kingsnorth AN. From ancient to contemporary times: a concise history of incisional hernia repair. *Hernia* 2012; 16: 1–7. doi: 10.1007/s10029-011-0870-5.
- Atema JJ, Furnée EJ, Maeda Y, et al. Major complex abdominal wall repair in contaminated fields with use of a non-cross-linked biologic mesh: a dual-institutional experience. *World J Surg* 2017; 41: 1993–1999. doi: 10.1007/s00268-017-3962-2.
- Bhangu A, Fitzgerald JE, Singh P, Battersby N, Marriott P, Pinkney T. Systematic review and meta-analysis of prophylactic mesh placement for prevention of incisional hernia following midline laparotomy. *Hernia* 2013; 17: 445–455. doi: 10.1007/s10029-013-1119-2.
- Timmermans L, De Goede B, Van Kempen BJH, Kazemier G, Jeekel J, Lange JF. Prevention of incisional hernia by means of primary mesh augmentation: a systematic review and meta-analysis. *Eur Surg Res* 2013; 50: 72.
- Ellis H, Bucknall TE, Cox PJ. Abdominal incisions and their closure. *Curr Problems Surg* 1985; 22: 4–51.
- Cox PJ, Ausobsky JR, Ellis H, Pollock AV. Towards no incisional hernias: lateral paramedian versus midline incisions. *J R Soc Med* 1986; 79: 711–712.
- Bucknall TE, Cox PJ, Ellis H. Burst abdomen and incisional hernia: a prospective study of 1129 major laparotomies. *Br Med J (Clin Res Ed)* 1982; 284: 931–933. doi: 10.1136/bmj.284.6320.931.

21. Sahlin S, Ahlberg J, Granström L, Ljungström KG. Monofilament versus multifilament absorbable sutures for abdominal closure. *Br J Surg* 1993; 80: 322-324. doi: 10.1002/bjbs.1800800318.
22. Luijendijk RW, Jeekel J, Storm RK, et al. The low transverse Pfannenstiel incision and the prevalence of incisional hernia and nerve entrapment. *Ann Surg* 1997; 225: 365. doi: 10.1097/00000658-199704000-00004.
23. Israelsson LA, Millbourn D. Prevention of incisional hernias: how to close a midline incision. *Surg Clin North Am* 2013; 93: 1027-1040. doi: 10.1016/j.suc.2013.06.009.
24. Bosanquet DC, Ansell J, Abdelrahman T, et al. Systematic review and meta-regression of factors affecting midline incisional hernia rates: analysis of 14 618 patients. *PLoS One* 2015; 10: e0138745. doi: 10.1371/journal.pone.0138745.
25. Goodenough CJ, Ko TC, Kao LS, et al. Development and validation of a risk stratification score for ventral incisional hernia after abdominal surgery: hernia expectation rates in intra-abdominal surgery (the HERNIA Project). *J Am Coll Surg* 2015; 220: 405-413. doi: 10.1016/j.jamcollsurg.2014.12.027.
26. Alnassar S, Bawahab M, Abdoh A, Guzman R, Al Tuwaijiri T, Louridas G. Incisional hernia postrepair of abdominal aortic occlusive and aneurysmal disease: five-year incidence. *Vascular* 2012; 20: 273-277. doi: 10.1258/vasc.2011.0a0332.
27. Fischer JP, Basta MN, Mirzabeigi MN, et al. A risk model and cost analysis of incisional hernia after elective, abdominal surgery based upon 12,373 cases: the case for targeted prophylactic intervention. *Ann Surg* 2016; 263: 1010-1017. doi: 10.1097/SLA.0000000000001394.
28. Basta MN, Mirzabeigi MN, Shubinetz V, Kelz RR, Williams NN, Fischer JP. Predicting incisional hernia after bariatric surgery: a risk stratification model based upon 2161 operations. *Surg Obes Relat Dis* 2016; 12: 1466-1473. doi: 10.1016/j.soard.2016.03.022.
29. Kirkpatrick AW, Nickerson D, Roberts DJ, et al. Intra-abdominal hypertension and abdominal compartment syndrome after abdominal wall reconstruction: quaternary syndromes? *Scand J Surg* 2017; 106: 97-106. doi: 10.1177/1457496916660036.
30. Schachtrupp A, Wetter O, Höer J. Influence of elevated intra-abdominal pressure on suture tension dynamics in a porcine model. *J Surg Res* 2019; 233: 207-212. doi: 10.1016/j.jss.2018.07.043.
31. Mathes T, Walgenbach M, Siegel R. Suture versus mesh repair in primary and incisional ventral hernias: a systematic review and meta-analysis. *World J Surg* 2016; 40: 826-835. doi: 10.1007/s00268-015-3311-2.
32. Strzelczyk J, Czupryniak L, Loba J, Wasiak J. The use of polypropylene mesh in midline incision closure following gastric by-pass surgery reduces the risk of postoperative hernia. *Langenbecks Arch Surg* 2002; 387: 294-297. doi: 10.1007/s00423-002-0325-7.
33. Pans A, Elen P, Dewé W, Desai C. Long-term results of polyglactin mesh for the prevention of incisional hernias in obese patients. *World J Surg* 1998; 22: 479-483.
34. Muysoms FE, Jairam A, López-Cano M, et al. Prevention of incisional hernias with biological mesh: a systematic review of the literature. *Front Surg* 2016; 3: 53. doi: 10.3389/fsurg.2016.00053.
35. López-Cano M, Pereira JA, Lozoya R, et al. PREBIOUS trial: a multicenter randomized controlled trial of PREventive midline laparotomy closure with a BIOabsorbable mesh for the prevention of incisional hernia: rationale and design. *Contemp Clin Trials* 2014; 39: 335-341. doi: 10.1016/j.cct.2014.10.009.
36. Timmermans L, Eker HH, Steyerberg EW, et al. Short-term results of a randomized controlled trial comparing primary suture with primary glued mesh augmentation to prevent incisional hernia. *Ann Surg* 2015; 261: 276-281. doi: 10.1097/SLA.0000000000000798.
37. Kohler A, Lavanchy JL, Lenoir U, Kurmann A, Candinas D, Beldi G. Effectiveness of prophylactic intraperitoneal mesh implantation for prevention of incisional hernia in patients undergoing open abdominal surgery: a randomized clinical trial. *JAMA Surg* 2019; 154: 109-115. doi: 10.1001/jamasurg.2018.4221.
38. Carbonell AM, Criss CN, Cobb WS, Novitsky YW, Rosen MJ. Outcomes of synthetic mesh in contaminated ventral hernia repairs. *J Am Coll Surg* 2013; 217: 991-998. doi: 10.1016/j.jamcollsurg.2013.07.382.
39. Majumder A, Winder JS, Wen Y, Pauli EM, Belyansky I, Novitsky YW. Comparative analysis of biologic versus synthetic mesh outcomes in contaminated hernia repairs. *Surgery* 2016; 160: 828-838. doi: 10.1016/j.surg.2016.04.041.
40. Rosen MJ, Bauer JJ, Harmaty M, et al. Multicenter, prospective, longitudinal study of the recurrence, surgical site infection, and quality of life after contaminated ventral hernia repair using biosynthetic absorbable mesh: the COBRA study. *Ann Surg* 2017; 265: 205-211. doi: 10.1097/SLA.0000000000001601.
41. Choi JJ, Palaniappa NC, Dallas KB, Rudich TB, Colon MJ, Divino CM. Use of mesh during ventral hernia repair in clean-contaminated and contaminated cases: outcomes of 33,832 cases. *Ann Surg* 2012; 255: 176-180. doi: 10.1097/SLA.0b013e31822518e6.
42. Argudo N, Pereira JA, Sancho JJ, Membrilla E, Pons MJ, Grande L. Prophylactic synthetic mesh can be safely used to close emergency laparotomies, even in peritonitis. *Surgery* 2014; 156: 1238-1244. doi: 10.1016/j.surg.2014.04.035.
43. Itani KM, Rosen M, Vargo D, Awad SS, DeNoto III G, Butler CE; RICH Study Group. Prospective study of single-stage repair of contaminated hernias using a biologic porcine tissue matrix: the RICH Study. *Surgery* 2012; 152: 498-505. doi: 10.1016/j.surg.2012.04.008.
44. Lykke A, Andersen JF, Jorgensen LN, Mynster T. Prevention of parastomal hernia in the emergency setting. *Langenbecks Arch Surg* 2017; 402: 949-955. doi: 10.1007/s00423-017-1596-3.
45. Lopez-Cano M, Garcia-Alamino JM, Antoniou SA, et al. EHS clinical guidelines on the management of the abdominal wall in the context of the open or burst abdomen. *Hernia* 2018; 22: 921-939. doi: 10.1007/s10029-018-1818-9.
46. Dietz UA, Wichelmann C, Wunder C, et al. Early repair of open abdomen with a tailored two-component mesh and conditioning vacuum packing: a safe alternative to the planned giant ventral hernia. *Hernia* 2012; 16: 451-460. doi: 10.1007/s10029-012-0919-0.
47. Poulou BK, Shelton J, Phillips S, et al. Epidemiology and cost of ventral hernia repair: making the case for hernia research. *Hernia* 2012; 16: 179-183. doi: 10.1007/s10029-011-0879-9.
48. Lauscher JC, Leonhardt M, Martus P, et al. Watchful waiting vs surgical repair of oligosymptomatic incisional hernias: current status of the AWARE study. *Chirurg* 2016; 87: 47-55. doi: 10.1007/s00104-015-0011-2.
49. Moschowitz AV. The pathogenesis and treatment of hernia of the linea alba. *Surg Genecol Obstet* 1914; 18: 504-507.
50. Sugrue M, Lawrence T, Ecker T. Fenestrated linea alba a potential trap in umbilical hernia repair beware! *Irish Journal of Medical Science* 2010; 179 (Suppl 9): S336; doi: 10.1007/s11845-010-0523-1.
51. de la Peña CG, Achirica CM, Domínguez-Adame E, Díez JM. Primary closure of laparotomies with high risk of incisional hernia using prosthetic material: analysis of usefulness. *Hernia* 2003; 7: 134-136. doi: 10.1007/s10029-003-0124-2.
52. Strzelczyk JM, Szymański D, Nowicki ME, Wilczyński W, Gaszynski T, Czupryniak L. Randomized clinical trial of postoperative hernia prophylaxis in open bariatric surgery. *Br J Surg Incorporating European Journal of Surgery and Swiss Surgery* 2006; 93: 1347-1350. doi: 10.1002/bjbs.5512.
53. El-Khadrawy OH, Moussa G, Mansour O, Hashish MS. Prophylactic prosthetic reinforcement of midline abdominal incisions in high-risk patients. *Hernia* 2009; 13: 267-274. doi: 10.1007/s10029-009-0484-3.
54. Bevis PM, Windhaber RA, Lear PA, Poskitt KR, Earnshaw JJ, Mitchell DC. Randomized clinical trial of mesh versus sutured wound closure after open abdominal aortic aneurysm surgery. *Br J Surg* 2010; 97: 1497-1502. doi: 10.1002/bjbs.7137.
55. Llaguna OH, Avgerinos DV, Nagda P, Elfant D, Leitman IM, Goodman E. Does prophylactic biologic mesh placement protect against the development of incisional hernia in high-risk patients? *World J Surg* 2011; 35: 1651-1655. doi: 10.1007/s00268-011-1131-6.
56. Abo-Ryia MH, El-Khadrawy OH, Abd-Allah HS. Prophylactic preperitoneal mesh placement in open bariatric surgery: a guard against incisional hernia development. *Obes Surg* 2013; 23: 1571-1574. doi: 10.1007/s11695-013-0915-1.
57. Curro G, Centorrino T, Low V, Sarra G, Navarra G. Long-term outcome with the prophylactic use of polypropylene mesh in morbidly obese patients undergoing biliopancreatic diversion. *Obes Surg* 2012; 22: 279-282. doi: 10.1007/s11695-011-0486-y.
58. Caro-Tarrago A, Casas CO, Salido AJ, Guileria ED, Fernandez FM, Guillen VV. Prevention of incisional hernia in midline laparotomy with an onlay mesh: a randomized clinical trial. *World J Surg* 2014; 38: 2223-2230. doi: 10.1007/s00268-014-2510-6.
59. Sarr MG, Hatcher NE, Snyder S, Hodde J, Carmody B. A prospective, randomized, multicenter trial of Surgisis Gold, a biologic prosthetic, as a sublay reinforcement of the fascial closure after open bariatric surgery. *Surgery* 2014; 156: 902-909. doi: 10.1016/j.surg.2014.06.022.
60. Bali C, Papakostas J, Georgiou G, et al. A comparative study of sutured versus bovine pericardium mesh abdominal closure after open abdominal aortic aneurysm repair. *Hernia* 2015; 19: 267-271. doi: 10.1007/s10029-014-1262-4.
61. Muysoms FE, Detry O, Vierendeels T, et al. Prevention of incisional hernias by prophylactic mesh-augmented reinforcement of midline laparotomies for abdominal aortic aneurysm treatment. *Ann Surg* 2016; 263: 638-645. doi: 10.1097/SLA.0000000000001369.
62. Caro-Tarrago A, Olona C, Millán M, Olona M, Espina B, Jorba R. Long-term results of a prospective randomized trial of midline laparotomy closure with onlay mesh. *Hernia* 2019; 23: 335-340. doi: 10.1007/s10029-019-01891-2.