Systematic Review and Meta-Regression of Factors Affecting Midline Incisional Hernia Rates: Analysis of 14,618 Patients

David C. Bosanquet1,*, James Ansell1, Tarig Abdelrahman2, Julie Cornish1, Rhiannon Harries3, Amy Stimpson4, Llion Davies1, James C. D. Glasbey5, Kathryn A. Frewer5, Natasha C. Frewer5, Daphne Russell6, Ian Russell6, Jared Torkington1

1 University Hospital of Wales, Cardiff, CF14 4XW, United Kingdom, 2 Royal Gwent Hospital, Newport, NP20 2UB, United Kingdom, 3 Morriston Hospital, Heol Maes Eglwys, Swansea, SA6 6NL, United Kingdom, 4 Glan Clwyd Hospital, Rhyi, LL18 5UJ, United Kingdom, 5 Cardiff University School of Medicine, Cardiff, CF14 4XN, United Kingdom, 6 Swansea University College of Medicine, Swansea, SA2 8AA, United Kingdom

* davebosanquet@hotmail.com

Abstract

Background
The incidence of incisional hernias (IHs) following midline abdominal incisions is difficult to estimate. Furthermore recent analyses have reported inconsistent findings on the superiority of absorbable versus non-absorbable sutures.

Objective
To estimate the mean IH rate following midline laparotomy from the published literature, to identify variables that predict IH rates and to analyse whether the type of suture (absorbable versus non-absorbable) affects IH rates.

Methods
We undertook a systematic review according to PRISMA guidelines. We sought randomised trials and observational studies including patients undergoing midline incisions with standard suture closure. Papers describing two or more arms suitable for inclusion had data abstracted independently for each arm.

Results
Fifty-six papers, describing 83 separate groups comprising 14,618 patients, met the inclusion criteria. The prevalence of IHs after midline incision was 12.8% (range: 0 to 35.6%) at a weighted mean of 23.7 months. The estimated risk of undergoing IH repair after midline laparotomy was 5.2%. Two meta-regression analyses (A and B) each identified seven characteristics associated with increased IH rate: one patient variable (higher age), two surgical variables (surgery for AAA and either surgery for obesity surgery (model A) or using an upper midline incision (model B)), two inclusion criteria (including patients with previous
laparotomies and those with previous IHs), and two circumstantial variables (later year of publication and specifying an exact significance level). There was no significant difference in IH rate between absorbable and non-absorbable sutures either alone or in conjunction with either regression analysis.

**Conclusions**

The IH rate estimated by pooling the published literature is 12.8% after about two years. Seven factors account for the large variation in IH rates across groups. However there is no evidence that suture type has an intrinsic effect on IH rates.

**Introduction**

Incisional hernias (IHs) are defined as “abdominal wall gaps around postoperative scars, perceptible or palpable by clinical examination or imaging” [1, 2]. They are a common complication of midline closure following abdominal surgery, cause significant morbidity, impair quality of life, and are costly to treat [3, 4]. Patient risk factors associated with a higher incidence (usually described as a higher “rate”) of IHs include diabetes mellitus [5], obesity [5, 6], cachexia [7], increasing age [6], male sex [6, 8], chronic obstructive pulmonary disease (COPD) [7, 9], history of (or operation for) an abdominal aortic aneurysm (AAA) [10], anaemia [7], smoking [8], and corticosteroids [11]. Surgical characteristics associated with greater IH formation include urgent surgery [12, 13], layered rather than mass closure [12, 14], and interrupted rather than continuous suture closure [15], whilst use of closure adjuncts such as prophylactic mesh may reduce IH rates [16]. Despite assessment by several meta-analyses, the effect of suture type (absorbable versus non-absorbable) on IH rates is not clear [13, 17–19]; and unsurprisingly suture preference varies from surgeon to surgeon. Identification of IHs may also depend on length of follow up [12, 20–22], and the use of radiological investigations in combination with clinical examination for diagnosis, rather than clinical examination alone [23–25].

The reported incidence of IHs after midline laparotomy ranges from 0 to 44%, reflecting the heterogeneity of patients, surgery and follow up. This variation makes service planning for IH repair difficult, and also hinders the design of randomised controlled trials (RCTs). The aims of this review were therefore threefold: firstly, to estimate a pooled IH rate following surgery via a midline laparotomy as derived from the published literature; secondly, to identify factors which can account for the wide variability in IH reporting; and thirdly, to examine the effect of suture type (absorbable versus non-absorbable) on preventing the occurrence of IHs.

**Methods**

We undertook a systematic review in accordance with PRISMA guidelines (see S1 File).[26] A detailed protocol and data abstraction proforma is available at https://wworth.swan.ac.uk/1624.aspx.

**Search strategy**

We (D.C.B., J.A., I.T.R. and J.T.) designed a search strategy with the help of a specialist librarian (see S2 File for MeSH terms used). We (J.C.D.G., K.A.F. and N.C.F.) searched Medline and Embase via Ovid, PubMed, the Cochrane Central Register of Controlled Trials and the Cochrane Database of Systematic Reviews from January 1980 until March 2013. There was no
restriction on publication type. We checked the references of included publications for other relevant papers.

**Paper selection**

Two reviewers (from T.A., J.A., J.C., L.D., R.H., A.S. and D.C.B.) independently screened each title and abstract. Another two of these reviewers retrieved and independently screened potentially relevant full papers; an experienced surgeon resolved discrepancies (J.T.). We included full papers published in English if they described a population of adult patients undergoing primary suture closure of a midline laparotomy wound, and reported number of IHs and average length of follow-up (mean or median). We excluded papers describing IH repair, non-midline abdominal incisions, or closure by methods other than primary sutures (e.g. prophylactic mesh placement or metal sutures), and papers which did not report length of follow-up were excluded. We included papers reporting patients with both midline and non-midline wounds only if they reported data on midline incisions separately. Randomised trials, quasi-experiments, cohort studies and case series were all eligible for inclusion. We compared multiple publications from single datasets, and used the most complete used for abstraction.

**Data abstraction**

We designed a proforma for data abstraction, piloted it on five papers, and refined it with input from all ten reviewers (D.C.B, T.A., J.A., J.C., R.H., A.S., L.D., J.C.D.G., K.A.F. and N.C. F.). Two reviewers (from T.A., J.A., J.C., R.H., A.S. and D.C.B.) independently abstracted data from each included paper; an experienced surgeon resolved discrepancies (J.T.). If papers reported IH rate and duration of follow-up separately for different patient groups (e.g. in RCTs with separate treatment arms), each patient group had data abstracted separately. We abstracted study characteristics (including exclusion criteria), patient demographics and comorbidity, type of surgical procedure undertaken, closure method, suture type, duration of follow up and number of IHs (S1 Table). We considered IHs present if assessed clinically or radiologically in accordance with consensus guidelines [2]. When papers reported attrition of patients due to mortality or loss to follow up, we used the number of patients at follow-up, rather than enrolment, as the denominator.

**Quality assessment**

We used the check list devised by Downs and Black to assess methodological quality [27]. This checklist can score both RCTs and observational studies on five methodological criteria: reporting (ten questions, eleven points), external validity (three questions, three points), bias (seven questions, seven points), confounding (six questions, eight points) and power (two questions, five points), with a maximum score of 34 (S3 File).

**Statistical analysis (D.R., I.T.R and D.C.B.)**

We collected and analysed all data in SPSS® version 20 (SPSS, Chicago, Illinois, USA). We summarised continuous data by means or medians, using the mean if both were available. We weighted these by number of patients to estimate IH rates. We derived confidence intervals (CI) from weighted T-tests or regression output. We used the Excel macro at: http://www.apho.org.uk/resource/view.aspx?RID=47241 to create funnel plots.

For meta-regression analysis we imputed missing variables by substituting weighted means [28]. We subtracted these weighted means from individual data for each variable to analyse data more accurately. We converted categorical study-level variables into binary variables (S1
We weighted regression analyses by number of patients using the ‘weighted least squares’ function in SPSS®.

We regressed all study characteristics separately against IH rate to select variables for inclusion in meta-regression models. To avoid omitting characteristics significant only in combination with other variables, we used a significance level of 20% to select candidates for the multivariable models. We undertook two complementary meta-regression analyses (‘stepwise' and ‘backwards elimination').

**Results**

**Overview**

The initial search yielded 3602 unique publications, of which 184 papers were retrieved for full review. We judged 56 (27 RCTs, 21 cohort studies, four quasi-experiments and four case series) eligible for inclusion (Fig 1). Several papers yielded abstractable data for more than one treatment arm generating 83 separate patient groups comprising 14,618 patients for analysis (Table 1). Fourteen RCTs and 15 cohort studies provided data for only a single patient group, for example by comparing midline with transverse laparotomy. Downs and Black scores ranged from 8 to 31 with a median of 21. Excluded papers included 11 duplicate publications [29–39] and one paper which met the inclusion criteria but reported an IH rate of 91% (20 of 22 patients) [40], which we excluded as an extreme outlier.

**Incisional hernia rates**

The mean IH rate was 12.8% (SD 7.7%; 95% CI: 11.4 to 14.2%) at a weighted mean follow-up time of 23.7 months. The funnel plot in Fig 2 shows a symmetrical spread of data around the

---

**Fig 1.** PRISMA diagram detailing search strategy and study selection process.

doi:10.1371/journal.pone.0138745.g001
| Study         | Year | Type of study | Data analysis | Diagnosis of IH | Number of surgeons or institutions | Consecutive patients? | Group Number | Number of pts | Number of IHs (%) | Follow-up (months): mean (default) or median | Downs & Black score [27] |
|--------------|------|---------------|---------------|-----------------|------------------------------------|-----------------------|--------------|---------------|-----------------|---------------------------------------------|----------------------------|
| Guillou [63] | 1980 | RCT           | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 58            | 4 (6.9)         | 12                                          | 20                          |
| Bucknall [50] | 1981 | RCT           | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 83            | 9 (10.8)        | 8.4                                         | 22                          |
| Cormon [52]  | 1981 | RCT           | Prospective   | NR              | Single institution                 | Yes                   | 1            | 49            | 4 (8.2)         | 19                                          | 20                          |
| Bucknall [64] | 1982 | Cohort study  | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 544           | 48 (8.8)        | 24                                          | 15                          |
| Shepherd [65] | 1983 | Cohort study  | Prospective   | NR              | Single institution                 | Yes                   | 1            | 200           | 10 (5.0)        | 24                                          | 11                          |
| Cox [66]     | 1986 | RCT           | Prospective   | Clinical        | Multiple institutions             | Yes                   | 1            | 159           | 20 (12.6)       | 12                                          | 20                          |
| McNeill [56] | 1986 | RCT           | Prospective   | NR              | NR                                 | NR                    | 1            | 51            | 5 (9.8)         | 18                                          | 21                          |
| Playforth [67] | 1986 | Case series   | Prospective   | Clinical        | Single surgeon                    | No                    | 1            | 56            | 6 (10.7)        | 30a                                         | 8                           |
| Cameron [53] | 1987 | RCT           | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 100           | 10 (10.0)       | 14.7                                        | 25                          |
| Krukowski [55] | 1987 | RCT           | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 285           | 22 (7.7)        | 12                                          | 23                          |
| Paes [68]    | 1987 | RCT           | Prospective   | NR              | Single institution                 | Yes                   | 1            | 51            | 2 (3.9)         | 15.2                                        | 17                          |
| Wissing [42] | 1987 | RCT           | Prospective   | Clinical        | Multiple institutions             | Yes                   | 1            | 286           | 48 (16.8)       | 12                                          | 24                          |
| Schoetz [69] | 1988 | Cohort study  | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 172           | 5 (2.9)         | 12                                          | 14                          |
| Khakin [70]  | 1991 | Cohort study  | Retrospective  | Clinical        | Single institution                 | Yes                   | 1            | 31            | 1 (3.2)         | 10a                                         | 18                          |
| Trimbos [71] | 1992 | RCT           | Prospective   | Clinical        | Multiple institutions             | NR                    | 1            | 122           | 7 (5.7)         | 12                                          | 24                          |
| Israelsson [57] | 1994 | Quasi-expt.   | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 325           | 49 (15.1)       | 12a                                         | 21                          |
| Carlson [54] | 1995 | RCT           | Prospective   | Clinical        | Multiple institutions             | Yes                   | 1            | 91            | 4 (4.4)         | 24                                          | 18                          |
| Gislason [72] | 1995 | RCT           | Prospective   | Clinical        | NR                                 | Yes                   | 1            | 412           | 30 (7.3)        | 12                                          | 22                          |
| Sivam [61]   | 1995 | Quasi-expt.   | Prospective   | NR              | Single institution                 | Yes                   | 1            | 358           | 14 (3.9)        | 12.3                                        | 13                          |
| Brolin [51]  | 1996 | RCT           | Prospective   | Clinical        | Single surgeon                    | NR                    | 1            | 109           | 20 (18.3)       | 28.3                                        | 14                          |
| Sugerman [41] | 1996 | Case series   | Retrospective  | Clinical        | Single institution                 | NR                    | 1            | 842           | 168 (20.0)      | 12                                          | 17                          |
| Colombo [73] | 1997 | RCT           | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 308           | 32 (10.4)       | 21                                          | 29                          |
| Adye [10]    | 1998 | Cohort study  | Retrospective  | Clinical        | Single institution                 | No                    | 1            | 58            | 18 (31.0)       | 12                                          | 18                          |
| Mingoli [12] | 1999 | Case series   | Retrospective  | Clinical        | Single institution                 | Yes                   | 1            | 138           | 25 (18.1)       | 11.2                                        | 17                          |

(Continued)
| Study                  | Year | Type of study | Data analysis | Diagnosis of IH | Number of surgeons or institutions | Consecutive patients? | Group Number | Number of pts | Number of IHs (%) | Follow-up (months): mean (default) or median | Downs & Black score [27] |
|-----------------------|------|---------------|---------------|-----------------|------------------------------------|-----------------------|--------------|---------------|-----------------|---------------------------------------------|--------------------------|
| Hsiao [74]            | 2000 | RCT           | Prospective   | Clinical        | Single surgeon                     | Yes                   | 1            | 93            | 5 (5.4)         | 24^a                          | 22                       |
| Musella [75]          | 2001 | Cohort study  | Retrospective  | Clinical and radiological | NR                          | NR                    | 1            | 51            | 16 (31.4)       | 48.6                         | 19                       |
| Lai [76]              | 2002 | Case series   | Retrospective  | NR              | Single institution                 | Yes                   | 1            | 19            | 3 (15.8)        | 27.3                         | 9                         |
| Strzelczyk [77]       | 2002 | Quasi-expl.   | Prospective   | Clinical        | NR                                  | Yes                   | 1            | 48            | 9 (18.8)        | 12                            | 13                       |
| Winslow [78]          | 2002 | RCT           | Prospective   | Clinical        | NR                                  | NR                    | 1            | 46            | 9 (19.6)        | 30.1                         | 21                       |
| Lim [79]              | 2003 | Cohort study  | Prospective   | NR              | Single institution                 | Yes                   | 1            | 92            | 2 (2.2)         | 20                            | 23                       |
| Raffetto [80]         | 2003 | Cohort study  | Prospective   | Clinical        | Multiple institutions              | Yes                   | 1            | 177           | 50 (28.2)       | 30.8                         | 21                       |
| Liapis [81]           | 2004 | Cohort study  | Prospective   | NR              | NR                                  | Yes                   | 1            | 197           | 32 (16.2)       | 63.7                         | 16                       |
| Marwha [82]           | 2005 | RCT           | Prospective   | NR              | Single institution                 | Yes                   | 1            | 50            | 15 (30.0)       | 6                             | 13                       |
| Ihedioha [83]         | 2008 | Cohort study  | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 63            | 10 (15.9)       | 22^a                         | 17                       |
| Lauret [84]           | 2008 | Cohort study  | Prospective   | NR              | Single institution                 | Yes                   | 1            | 165           | 46 (27.9)       | 51^a                         | 22                       |
| Singh [85]            | 2008 | Cohort study  | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 74            | 13 (17.6)       | 21.9                         | 19                       |
| Togo [86]             | 2008 | Cohort study  | Prospective   | Clinical or radiological | Single institution            | No                    | 1            | 95            | 6 (6.3)         | 52.8                         | 23                       |
| El-Khadrawy [87]      | 2009 | RCT           | Prospective   | Radiological    | Single institution                 | NR                    | 1            | 20            | 3 (15.0)        | 36.3                         | 20                       |
| Halm [88]             | 2009 | RCT           | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 63            | 9 (14.3)        | 12^a                         | 29                       |
| Milbourn [89]         | 2009 | RCT           | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 272           | 49 (18.0)       | 12                            | 30                       |
| Seiler [15]           | 2009a| RCT           | Prospective   | Clinical and radiological | Multiple institutions  | NR                    | 2            | 250           | 14 (5.6)        | 12^a                         |                          |
|                      |      |               |               |                 |                                     |                       | 1            | 176           | 28 (15.9)       | 12                            |                          |
|                      |      |               |               |                 |                                     |                       | 2            | 178           | 15 (8.4)        | 12                            |                          |
|                      |      |               |               |                 |                                     |                       | 3            | 176           | 22 (12.5)       | 12                            |                          |
| Seiler [90]           | 2009b| RCT           | Prospective   | Clinical and radiological | Single institution          | NR                    | 1            | 79            | 13 (16.5)       | 12                            | 27                       |
| Veljkovic [91]        | 2009 | Cohort study  | Prospective   | Clinical        | Single institution                 | No                    | 1            | 603           | 81 (13.4)       | 6.9                           | 24                       |
| Al-Dahamasah [92]     | 2010 | Cohort study  | Prospective   | Clinical and radiological | Single institution        | NR                    | 1            | 284           | 16 (5.6)        | 20.6                          | 17                       |
| Berretta [93]         | 2010 | RCT           | Prospective   | Clinical and radiological | Single institution        | NR                    | 1            | 63            | 6 (9.5)         | 36                            | 25                       |
|                      |      |               |               |                 |                                     |                       | 2            | 63            | 4 (6.3)         | 36                            |                          |
|                      |      |               |               |                 |                                     |                       | 3            | 65            | 7 (10.8)        | 36^a                         | 13                       |
| Bevis [16]            | 2010 | RCT           | Prospective   | Clinical and radiological | Multiple institutions  | Yes                    | 1            | 45            | 16 (35.6)       | 20.3                          | 22                       |
| Skipworth [94]        | 2010 | Cohort study  | Prospective   | Clinical        | Single institution                 | Yes                   | 1            | 167           | 10 (6.0)        | 36^a                         | 13                       |
| Bloemen [23]          | 2011 | RCT           | Prospective   | Clinical or radiological | Single institution      | Yes                   | 1            | 233           | 45 (20.2)       | 34.5                          | 30                       |
|                      |      |               |               |                 |                                     |                       | 2            | 233           | 58 (24.9)       | 33.3                          |                          |

(Continued)
mean, but greater than would be expected if the underlying IH rate were constant. The largest patient group (with 842 patients) had an IH rate substantially above the expected range [41]; these patients all underwent gastric bypass surgery for morbid obesity, with thus a greater predicted IH rate. The two largest studies enrolled 1156 and 1065 patients, with IH rates of 15.3% [42] and 11.7% [43] respectively. Both would fall within the boundary in Fig 2 showing two standard errors, but do not appear at these points because data were abstracted as four and two groups respectively.

Study characteristics and incisional hernia rates

IH rates were comparable between: RCTs and non-RCTs (12.3 versus 13.2%; 95% CI for difference: -3.8 to 1.8%; p = 0.49); papers reporting consecutive patients or not (12.6 versus 14.8%; 95% CI for difference: -7.9 to 3.6%; p = 0.46); and studies enrolling elective patients or elective and emergency patients (13.1 versus 13.0%; 95% CI for difference: -3.1 to 3.3%; p = 0.95). Retrospective studies reported significantly greater IH rates than prospective studies (17.3 versus 12.1%; 95% CI for difference: 1.2 to 9.2%; p = 0.012). IH rates were greater, but not significantly greater, in studies that included patients with previous IHs (15.3 versus 12.7%; 95% CI for difference: -1.0 to 6.1%; p = 0.15) and patients on steroids (14.9 versus 11.6%; 95% CI for difference: -1.3 to 7.9%; p = 0.16). Studies that included patients with previous laparotomies had a significantly greater IH rate (15.0 versus 11.5%; 95% CI for difference: 0.1 to 6.9%; p = 0.043). IH rates detected clinically were similar to those diagnosed clinically or radiologically (12.614.6%; 95% CI for difference: -5.1 to 1.1%; p = 0.22).

| Study          | Year | Type of study | Data analysis | Diagnosis of IH          | Number of surgeons or institutions | Consecutive patients? | Group Number | Number of pts | Number of IHs (%) | Follow-up (months): mean (default) or median | Downs & Black score |
|---------------|------|---------------|---------------|--------------------------|-----------------------------------|----------------------|--------------|--------------|------------------|---------------------------------------------|---------------------|
| deSouza [95]  | 2011 | Cohort study  | Retrospective  | Clinical or radiological | Single institution                | Yes                   | 1            | 142          | 28 (19.7)        | 21.2                                        | 25                  |
| Justinger [96] | 2011 | Quasi-expt.   | Prospective   | Clinical or radiological | Single institution                | Yes                   | 1            | 399          | 56 (14.0)        | 36a                                         | 21                  |
| Klarenbeek [97]| 2011 | RCT           | Prospective   | NR                        | Multiple institutions            | Yes                   | 1            | 52           | 2 (3.8)          | 6                                           | 23                  |
| Llaguna [98]  | 2011 | Cohort study  | Prospective   | Clinical                  | Single surgeon                   | NR                    | 1            | 62           | 11 (17.7)        | 17.7                                        | 19                  |
| Salayta [99]  | 2011 | Cohort study  | Prospective   | Clinical or radiological  | Single institution                | NR                    | 1            | 284          | 16 (5.6)         | 24                                           | 23                  |
| Albertsneier [100]| 2012| RCT           | Prospective   | Clinical and radiological | Multiple institutions            | NR                    | 1            | 112          | 21 (18.8)        | 12                                           | 25                  |
| Gruppo [43]   | 2012 | Cohort study  | Prospective   | Clinical                  | Single institution                | Yes                   | 1            | 412          | 51 (12.4)        | 67.2                                        | 20                  |
| Lee [101]     | 2012 | Cohort study  | Prospective   | Clinical or radiological  | Single institution                | No                    | 1            | 68           | 20 (29.4)        | 28.2a                                        | 18                  |

* Median
Quasi-expt. Quasi-experimental study
NR Not reported

Note For RCTs or observational studies with more than one group, we specify individual patient numbers, IH rates and follow-up time for each group; for some RCTs or observational studies, however, we abstracted only one group, either because only one met the inclusion criteria, or because we could not abstract two groups independently.

doi:10.1371/journal.pone.0138745.t001

Table 1. (Continued)
We used year of publication as a proxy for date of surgery: reported IH rates increased with year of publication (Table 2 and Fig 3; p = 0.033). Duration of follow up was significantly longer in non-RCTs than in RCTs (29.2 months versus 16.8 months; p = 0.001). Nevertheless this had no significant effect on reported IH rates (p = 0.59). Downs and Black scores also did not predict IH rates.

Regression analyses

S2 Table lists the study characteristics which we abstracted and specifies the binary variables into which we disaggregated categorical variables. Twenty-two of these achieved the significance level of 20% to become candidates for the meta-regression models. Table 2 shows the results of regressing IH rate on each of these. Significance levels before and after imputing missing data were very similar, with an identical choice of variables for the multivariable meta-regression analyses.

We undertook two complementary pre-specified meta-regression analyses using backward elimination and stepwise regression (Table 3, models A and B). Each model identified seven significant study or patient characteristics that together predicted higher IH rates (including six common variables and one of two others): five apparently causal—inclusion of patients with previous laparotomies, inclusion of patients with previous IHs, higher mean (or median) age of patients, surgery for AAA and either surgery for obesity (model A) or upper midline incision (model B); and two circumstantial—later year of publication, and reporting exact significance levels. Both models significantly improved on models with fewer predictors, and achieved impressive, and very similar, adjusted R² (0.403 and 0.404 respectively).

The effect of suture material on IH rates

Almost all papers provided data on type of suture used for midline closure, yielding a subset of 75 patient groups comprising 13,157 patients, of whom 25.5% received non-absorbable sutures, 56.2% slowly absorbable, and 18.3% rapidly absorbable. Univariable analysis showed no significant difference (p = 0.54) between absorbable and non-absorbable sutures (IH rates of 13.5 and 11.9% respectively; 95% CI for difference: -2.0 to 5.1%). Forcing suture type into either multivariable model did not affect other regression coefficients, and suture type remained non-
### Continuous (patient level) variables

| Variable                                | Number of included groups (patients) | Weighted mean | Number of zero value papers: groups (patients) | Coefficient B (SE) | 95% CI for B | Univariable significance level |
|-----------------------------------------|--------------------------------------|----------------|-----------------------------------------------|-------------------|--------------|-------------------------------|
| Males                                   | 38 (5761)                            | 39.5%          | 11 (1876)                                     | 10.71 (3.41)      | 3.94 to 17.49 | 0.002                         |
| Gynaecological surgery                  | 51 (7672)                            | 23.6%          | 41 (5859)                                     | -6.57 (2.16)      | -10.88 to -2.25 | 0.003                         |
| AAA surgery                             | 47 (6968)                            | 10.6%          | 42 (6255)                                     | 8.69 (3.17)       | 2.38 to 14.99  | 0.008                         |
| Age (mean or median)                    | 57 (9370)                            | 58.7 years     | 0 (0)                                         | 0.20 (0.76)       | 0.049 to 0.35  | 0.010                         |
| Lower midline incision                  | 40 (6026)                            | 27.4%          | 28 (4006)                                     | -5.65 (2.58)      | -10.79 to -0.51 | 0.031                         |
| Year of publication (from 1980)         | 83 (14146)                           | 19.9 years     | 1 (58)                                        | 0.16 (0.67)       | 0.12 to 0.28   | 0.033                         |
| Upper midline incision                  | 40 (6026)                            | 26.1%          | 25 (4210)                                     | 5.45 (2.53)       | 0.42 to 10.47  | 0.034                         |
| Vascular surgery                        | 49 (7216)                            | 25.6%          | 37 (5318)                                     | 3.90 (2.26)       | -0.59 to 8.38  | 0.088                         |

### Categorical (study level) variables

| Variable                                | Number of included groups (patients) | Coefficient B (SE) | 95% CI for B | Univariable significance level |
|-----------------------------------------|--------------------------------------|-------------------|--------------|-------------------------------|
| Prospective (vs. retrospective) data collection | 83 (14146)                            | -5.21 (2.02)      | -9.24 to -1.18 | 0.012                         |
| Obesity surgery                         | 83 (14146)                            | 5.28 (2.42)       | 0.47 to 10.09  | 0.032                         |
| Includes patients with previous laparotomies | 46 (9913)                            | 3.51 (1.70)       | 0.12 to 6.90   | 0.043                         |
| Includes patients with existing IHs     | 41 (8931)                            | 2.59 (1.78)       | -0.95 to 6.12  | 0.150                         |
| Includes patients on steroids           | 40 (6439)                            | 3.29 (2.31)       | -1.30 to 7.88  | 0.158                         |

### Downs & Black [27] criteria (study level)

| Variable                                | Number of included groups (patients) | Coefficient B (SE) | 95% CI for B | Univariable significance level |
|-----------------------------------------|--------------------------------------|-------------------|--------------|-------------------------------|
| Similar follow up between groups        | 83 (14146)                            | 6.01 (1.76)       | 2.51 to 9.51  | 0.001                         |
| Appropriate statistical analyses        | 83 (14146)                            | 5.74 (1.69)       | 2.38 to 9.09  | 0.001                         |
| Exact significance levels specified     | 83 (14146)                            | 6.24 (1.99)       | 2.28 to 10.19 | 0.002                         |
| Outcomes clearly described              | 83 (14146)                            | 6.29 (2.16)       | 1.99 to 10.59 | 0.005                         |
| Sufficient follow up                    | 83 (14146)                            | 6.63 (2.66)       | 1.35 to 11.91 | 0.015                         |
| Outcomes measured with a valid test     | 83 (14146)                            | 5.32 (2.17)       | 1.01 to 9.63  | 0.016                         |
| Sufficient data given                   | 83 (14146)                            | 3.02 (1.47)       | 1.00 to 5.93  | 0.043                         |
| Clear hypothesis                        | 83 (14146)                            | 4.85 (2.54)       | -0.21 to 9.91 | 0.060                         |
| Recruits representative of sample population | 83 (14146)                            | -3.40 (1.98)      | -7.34 to 0.55 | 0.091                         |

doi:10.1371/journal.pone.0138745.t002
significant. Several sensitivity analyses failed to find any subpopulation where suture type affects IH rates (Table 4). Rapidly absorbed sutures showed the highest IH rate (15.6%), but not significantly higher than either slowly absorbable (13.0%; 95% CI for difference: -1.6% to 6.9%; \(p = 0.234\)), or non-absorbable (11.9%; 95% CI for difference: -1.7 to 8.9%; \(p = 0.170\)) sutures, consistent with published analyses [13, 17].

Other outcomes

Of those with IHs, 49.0% (95% CI: 18.4 to 79.6%) were symptomatic, and 36.0% (95% CI: 21.1 to 50.9%) underwent IH repair. The risk of patients requiring IH repair after a midline laparotomy was 5.2% (95% CI: 2.8 to 7.7%). The use of non-absorbable sutures had no effect on the

**Table 3. Regression analyses of IH rates on multiple predictors.**

| Variables (in order of significance level)                                      | Coefficient B (SE) | 95% CI for B     | Significance level |
|--------------------------------------------------------------------------------|--------------------|------------------|-------------------|
| **Model A—backwards elimination**                                             |                    |                  |                   |
| Includes patients with previous laparotomies                                  | 6.09 (1.49)        | 3.12 to 9.05     | <.001             |
| Exact significance levels specified                                           | 4.93 (1.73)        | 1.49 to 8.38     | 0.006             |
| Age (mean or median)                                                          | 0.20 (0.072)       | 0.057 to 0.35    | 0.007             |
| Year of publication (from 1980)                                               | 0.16 (0.064)       | 0.029 to 0.28    | 0.017             |
| Obesity surgery                                                               | 4.86 (2.03)        | 0.93 to 9.53     | 0.019             |
| AAA surgery                                                                   | 6.43 (2.80)        | 0.84 to 12.01    | 0.025             |
| Study includes patients with existing IHs                                      | 3.01 (1.49)        | 0.042 to 5.98    | 0.047             |
| **Model B—stepwise**                                                          |                    |                  |                   |
| Includes patients with previous laparotomies                                  | 6.02 (1.49)        | 3.05 to 9.00     | <.001             |
| Exact significance levels specified                                           | 5.17 (1.72)        | 1.74 to 8.59     | 0.004             |
| Age (mean or median)                                                          | 0.20 (0.072)       | 0.053 to 0.34    | 0.008             |
| Year of publication (from 1980)                                               | 0.16 (0.064)       | 0.028 to 0.28    | 0.017             |
| Upper midline incision                                                        | 5.23 (2.16)        | 0.93 to 9.53     | 0.018             |
| AAA surgery                                                                   | 6.62 (2.81)        | 1.01 to 12.20    | 0.021             |
| Includes patients with existing IHs                                            | 2.66 (1.52)        | -0.37 to 5.68    | 0.084             |

Notes: Model A: significance level for exclusion = 5%
Model B: significance level for inclusion = 10%; significance level for exclusion = 12%

doi:10.1371/journal.pone.0138745.t003
likelihood of IHs being symptomatic or undergoing repair (p = 0.95 and p = 0.49 respectively). Stitch sinuses occurred in 1.8% of patients (95% CI: 0.8 to 2.9%); these were more likely, but not significantly more likely, with non-absorbable suture material (p = 0.057). Wound infections occurred in 8.7% of patients, but these did not affect the incidence of IHs (p = 0.22).

Discussion

This systematic review and meta-regression of 14,618 patients from 83 patient groups has demonstrated a weighted mean IH rate of 12.8% at a weighted mean of 23.7 months follow-up after surgery via a midline laparotomy. Approximately one half of IHs are symptomatic; and about one third undergo repair. The risk of needing further surgery for IH after a midline incision is approximately 5%.

Our search strategy sought all available evidence on the epidemiology of IH, notably by including all recognised research designs, both randomised and not. Although trials generally provide the best evidence for evaluating effectiveness, they are less well suited to assessing risk factors; they tend, not only to have narrow inclusion criteria, but also to restrict length of follow-up. Fortunately our rigorous analysis generated well-behaved statistical models characterising the influence of a range of methodological, patient and surgical variables. In particular, though the mean duration of follow-up in trials (16.8 months) was significantly shorter than in other designs (29.2 months), the mean IH rate was very similar (12.3% versus 13.2%).

Two consistent meta-regression models have each identified seven independent factors associated with increased IH rate—one patient variable (higher age), two surgical variables (surgery for AAA and either surgery for obesity surgery (model A) or using an upper midline incision (model B)), two inclusion criteria (including patients with previous laparotomies and those with previous IHs), and two circumstantial variables (later year of publication and specifying an exact significance level). Suture type had no effect on IH rates.

To our knowledge this meta-regression is the only such analysis of midline abdominal incisions to date. Data abstraction was preferentially at the time of outpatient assessment, rather than patient enrolment, thus excluding early post-operative mortality and loss to follow up, thereby giving a more clinically relevant rate. Several studies excluded established high-risk groups, including those on steroids or with previous IHs. This suggests that an unselected cohort more representative of day-to-day surgical practice would suffer an even greater incidence of IHs.

Table 4. Univariable regression of suture type (absorbable or non-absorbable) on IH rates.

| Analysis                        | Number of groups (patients) | Significance level | B (95% CI for B)       |
|---------------------------------|-----------------------------|--------------------|------------------------|
| All studies                     | 75 (13157)                  | 0.544              | -1.06 (-4.54 to 2.41)  |
| Randomised trials               | 45 (6485)                   | 0.925              | 0.20 (-4.11 to 4.51)   |
| Multiple site studies           | 17 (2724)                   | 0.881              | 0.61 (-7.92 to 9.14)   |
| Includes previous laparotomy    | 29 (6001)                   | 0.929              | -0.28 (-6.60 to 6.04)  |
| Includes previous IH            | 22 (4603)                   | 0.818              | -0.77 (-7.70 to 6.15)  |
| Includes emergency surgery      | 35 (7383)                   | 0.927              | 0.23 (-4.78 to 5.24)   |
| Continuous closure              | 59 (9875)                   | 0.921              | 0.28 (-4.14 to 4.70)   |
| Studies with comparative dataa  | 51 (10441)                  | 0.900              | 0.02 (-3.83 to 4.35)   |
| Downs & Black score ≥21         | 46 (8888)                   | 0.619              | 1.12 (-3.38 to 5.61)   |

*a* Studies with more than one patient group available for analysis.

Summary Suture type (absorbable versus non-absorbable) had no effect on IH rates.

doi:10.1371/journal.pone.0138745.t004
The patient variables we identified as associated with IHs are consistent with previous reports. Increasing age is known to be a risk factor for IHs [6], as is bariatric surgery [5, 6] and a history of (or operation for) an AAA [44]. The use of an upper-midline incision has not been studied in isolation as a risk factor for IHs; as it was significantly correlated with bariatric surgery, however, these incisions may act as a proxy for open obesity surgery. Several patient variables were significant in other studies but not here, for example male sex [6, 8] (significant only in univariable analysis), or a history of diabetes [5] (not significant at any stage). Although postoperative infection has previously shown correlation with increased IH rates [21], this study showed no such association. The absence of all these variables from the final model has three possible explanations: they are correlated with other significant predictors; they are not reported in all studies, or otherwise difficult to abstract; or meta-regression can distort relationships because it averages patient characteristics within single data points [45].

The later the year of publication, the more reported IH rates increased. There are many plausible explanations for this association: operating on patients at greater risk of IHs; more rigorous follow up and diagnosis; better reporting over time; or gradual change in surgical technique. Nevertheless IHs appear more prevalent in modern surgical practice than previously.

In both univariable and multivariable analyses, reporting exact significance levels (rather than reporting a result as “not significant” or “p less than” a specified value) was associated with significantly higher IH rates. Whilst surprising that a simple change from vague to specific probability statement had such an effect, especially as the Downs and Black quality score had no effect on IH rates, it was a highly significant variable in both regression models. It may be that this variable is simply a proxy for methodological and reporting rigour, similar to other such ‘effect modifiers’ noted in previous meta-regression analyses [46]. This finding highlights the value of standardised significance level reporting in the literature.

The length of follow up had no apparent effect on IH rates. This finding is contrary to previous publications showing that rates at one year underestimate the overall burden of IHs. For example Fink’s review of 775 patients enrolled in two RCTs showed IH rates increased from 12.6% at one year to 22.4% at three years [22]. Similarly Hoer et al. followed patients for ten years, and found 54% of IH developed after twelve months, 75% after two years and 89% after five years [6]. However our meta-regression did not show this effect, probably because we had to analyse data grouped by study, rather than individual data; so other differences between studies may have obscured the effect of duration of follow up. The estimated IH rate herein corresponds with an average follow-up time of approximately two years. According to Hoer et al. [6], about 75% of IH would be clinically apparent at this point. This equates with an IH rate of approximately 17% at ten years. While early studies may underestimate the long-term incidence of IH, IHs that develop later are generally smaller and cause few symptoms [47].

Despite numerous RCTs and several meta-analyses, there is little consensus in choosing between absorbable and non-absorbable sutures for midline closure [48]. Addressing this issue is useful, as suture type is more readily altered than many other variables. Both have potential problems: absorbable sutures lose their tensile strength with time and thus fail to support marginal scar tissue; whereas non-absorbable sutures have a theoretically greater risk of “button-holing” the rectus sheath by repeated ‘sawing’ through the fascia with abdominal wall movement [49]. RCTs have reported conflicting results on reducing IHs: some favour non-absorbable sutures [42, 50]; others favour absorbable sutures [51, 52], but most show no difference [23, 53–57]. Meta-analyses also report conflicting results: Weiland et al. (eight trials; n = 3607 including non-midline incisions) [19], Rucinski et al. (fifteen trials; n = 5851) [58] and Hodgeson et al. (sixteen trials; n = 5028) [18], found non-absorbable sutures better at reducing IH rates. In contrast Salid et al. (eight trials; n = 4261) [59], Van Riet et al. (five trials of slowly absorbing versus non-absorbing material; n = 2669) [17] and Diener et al. (six trials
of emergency and elective patients (n = 3219) [13] found no difference in IH rates with suture type. Our meta-regression has confirmed that suture material does not affect IH rates whether analysed alone or in combination with other significant factors. However there was a non-significant tendency for non-absorbable sutures to increase the rate of suture sinuses. As neither material reduces IH formation, surgeons may prefer slowly absorbable sutures [60] to reduce post-operative pain [20] and suture sinus formation [17, 23].

Finally our analysis unequivocally identifies patient groups at high risk of IH: elderly patients; those undergoing AAA or obesity surgery; and patients with previous laparotomies or IHs. Though our review did not have the power to identify the best treatment for these minority groups, we conclude that they need special consideration and possible change in technique, for example prophylactic placement of mesh or more complex forms of suture closure such as the 'Hughes repair' (also known as the 'Cardiff near-and-far' or 'Smead-Jones' repair) [61, 62].

Conclusions
IHs are an increasingly reported problem in surgical practice, with an estimated rate of 12.8% in published studies. This rate is likely to be greater in general surgical practice. Factors affecting reported IH rates include patient characteristics, surgical characteristics, inclusion criteria, and circumstantial reporting factors. However there is no evidence that absorbable and non-absorbable sutures differ in their effects on IH rates.

Supporting Information
S1 File. PRISMA checklist.
(DOCX)
S2 File. Search criteria used.
(DOCX)
S3 File. Quality scoring system by Downs and Black [27].
(DOCX)
S1 Table. Complete list of variables extracted from each paper, typically as percentages.
(DOCX)

Author Contributions
Conceived and designed the experiments: DCB JA JC RH AS LD JCDG KAF NCF DR IR JT. Performed the experiments: DCB JA TA JC RH AS LD JCDG KAF. Analyzed the data: DCB DR IR JT. Contributed reagents/materials/analysis tools: DCB DR IR JT. Wrote the paper: DCB JA JC RH AS LD JCDG KAF NCF DR IR JT.

References
1. Korenkov M, Paul A, Sauerland S, Neugebauer E, Arndt M, Chevrel JP, et al. Classification and surgical treatment of incisional hernia. Results of an experts' meeting. Langenbecks Arch Surg. 2001; 386: 65–73. PMID: 11405092
2. Muysoms FE, Miserez M, Berrevoet F, Campanelli G, Champault GG, Chelala E, et al. Classification of primary and incisional abdominal wall hernias. Hernia. 2009; 13: 407–14. doi: 10.1007/s10029-009-0518-x PMID: 19495920
3. Burger JW, Luijendijk RW, Hop WC, Halm JA, Verdaasdonk EG, Jeekel J. Long-term follow-up of a randomized controlled trial of suture versus mesh repair of incisional hernia. Ann Surg. 2004; 240: 578–83. PMID: 15383785
4. van Ramshorst GH, Eker HH, Hop WC, Jeekel J, Lange JF. Impact of incisional hernia on health-related quality of life and body image: a prospective cohort study. Am J Surg. 2012; 204: 144–50. doi: 10.1016/j.amjsurg.2012.01.012 PMID: 22579232

5. Franchi M, Ghezzi F, Buttarelli M, Tateo S, Balestrieri D, Bolis P. Incisional hernia in gynecologic oncology patients: A 10-year study. Obstet Gynecol. 2001; 97: 696–700. PMID: 11339918

6. Hoer J, Lawong G, Klinge U, Schumpelick V. Factors influencing the development of incisional hernia. A retrospective study of 2,983 laparotomy patients over a period of 10 years. Chirurg. 2002; 73: 474–80. PMID: 12089832

7. Makela JT, Kiviniemi H, Juvenon T, Laitinen S. Factors influencing wound dehiscence after midline laparotomy. Am J Surg. 1995; 170: 387–90. PMID: 7573734

8. Sorensen LT, Hernmingsen UB, Kirkeby LT, Kallehave F, Jorgensen LN. Smoking is a risk factor for incisional hernia. Arch Surg. 2005; 140: 119–23. PMID: 15723991

9. Adell-Carceller R, Segarra-Soria MA, Pellicer-Castell V, Marcote-Valdivieso E, Gamon-Giner R, Martin-Franco MA, et al. Incisional hernia in colorectal cancer surgery. Associated risk factors. Cir Esp. 2006; 73: 42–5. PMID: 16426532

10. Adye B, Luna G. Incidence of abdominal wall hernia in aortic surgery. Am J Surg. 1998; 175: 400–2. PMID: 9600287

11. Junge K, Klinge U, Klosterhalfen B, Rosch R, Stumpf M, Schumpelick V. Review of wound healing with reference to an unreparable abdominal hernia. Eur J Surg. 2002; 168: 67–73. PMID: 12113273

12. Mingoli A, Puggioni A, Sgarzini G, Luciani G, Corzani F, Ciccarone F, et al. Incidence of incisional hernia following emergency abdominal surgery. Ital J Gastroenterol Hepatol. 1999; 31: 449–53. PMID: 10575660

13. Diener MK, Voss S, Jensen K, Buchler MW, Seiler CM. Elective midline laparotomy closure: the INLINE systematic review and meta-analysis. Ann Surg. 2010; 251: 843–56. doi:10.1097/SLA.0b013e3181d973e4 PMID: 20395846

14. Kendall SW, Brennan TG, Guillou PJ. Suture length to wound length ratio and the integrity of midline and lateral paramedian incisions. Br J Surg. 1991; 78: 705–7. PMID: 2070239

15. Seiler CM, Bruckner T, Diener MK, Papyan A, Golcher H, Seidlmayer C, et al. Interrupted or continuous slowly absorbable sutures for closure of primary elective midline abdominal incisions: a multicenter randomized trial (INSECT). Ann Surg. 2009; 249: 576–82. doi:10.1097/SLA.0b013e31819ec6c8 PMID: 19300233

16. 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: 1497–502. doi: 10.1002/bjs.7137 PMID: 20603858

17. van ’t Riet M, Steyerberg EW, Nellensteyn J, Bonjer HJ, Jeekel J. Meta-analysis of techniques for closure of midline abdominal incisions. Br J Surg. 2002; 89: 1350–6. PMID: 12390373

18. Hodgson NC, Malthaner RA, Ostbye T. The search for an ideal method of abdominal fascial closure: a meta-analysis. Ann Surg. 2000; 230: 436–42. PMID: 10714638

19. Weiland DE, Bay RC, Del Sordi S. Choosing the best abdominal closure by meta-analysis. Am J Surg. 1998; 176: 666–70. PMID: 9926810

20. Ceydeli A, Rucinski J, Wise L. Finding the best abdominal closure: an evidence-based review of the literature. Curr Surg. 2005; 62: 220–5. PMID: 15796944

21. Mudge M, Harding KG, Hughes LE. Incisional hernia. Br J Surg. 1986; 73: 82.

22. Fink C, Baumann P, Wente MN, Knebel P, Bruckner T, Ulrich A, et al. Incisional hernia rate 3 years after midline laparotomy. Br J Surg. 2014; 101: 51–4. doi: 10.1002/bjs.9364 PMID: 24281948

23. Bloemen A, van Dooren P, Huizinga BF, Hoofwijk AG. Randomized clinical trial comparing polypropylene or polydioxanone for midline abdominal wall closure. Br J Surg. 2011; 98: 633–9. doi:10.1002/bjs.7398 PMID: 21254041

24. Ghahremani GG, Jimenez MA, Rosenfeld M, Rochester D. CT diagnosis of occult incisional hernias. Am J Roentgenol. 1987; 148: 139–42.

25. Lassandro F, Iasiello F, Pizza NL, Valente T, Stefano ML, Grassi R, et al. Abdominal hernias: Radiological features. World J Gastrointest Endosc. 2011; 3: 110–7. doi:10.4253/wjge.v3.i6.110 PMID: 21860678

26. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009; 339: 2535.

27. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health. 1998; 52: 377–84. PMID: 9764259
28. Harrell FE Jr, Lee KL, Mark DB. Multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. Stat Med. 1996; 15: 361–87. PMID: 866867

29. Bloemen A, van Dooren P, Huizinga BF, Hoofwijk AG. Comparison of ultrasonography and physical examination in the diagnosis of incisional hernia in a prospective study. Hernia. 2012; 16: 53–7. doi: 10.1007/s10029-011-0865-2 PMID: 21833852

30. Israelsson LA, Wimo A. Cost minimisation analysis of change in closure technique of midline incisions. Eur J Surg. 2000; 166: 642–6. PMID: 11003434

31. Israelsson LA, Wimo A. Incisional hernias in patients with aortic aneurysmal disease: the importance of suture technique. Eur J Vasc Endovasc Surg. 1999; 17: 133–5. PMID: 10063408

32. Israelsson LA, Jonsson T. Overweight and healing of midline incisions: the importance of suture technique. Eur J Surg. 1997; 163: 175–80. PMID: 9085058

33. Israelsson LA, Jonsson T, Knutsson A. Suture technique and healing in midline laparotomy incisions. Eur J Surg. 1996; 162: 605–9. PMID: 8891617

34. Israelsson LA, Jonsson T. Suture length to wound length ratio and healing of midline laparotomy incisions. Br J Surg. 1993; 80: 1284–6. PMID: 8242299

35. Israelsson LA, Jonsson T. Incisional hernia after midline laparotomy: a prospective study. Eur J Surg. 1996; 162: 125–9. PMID: 9639725

36. Lamont PM, Ellis H. Incisional hernia in re-opened abdominal incisions: an overlooked risk factor. Br J Surg. 1988; 75: 374–6. PMID: 3359154

37. Millbourn D, Cengiz Y, Israelsson LA. Risk factors for wound complications in midline abdominal incisions related to the size of stitches. Hernia. 2011; 15: 261–6. doi: 10.1007/s10029-010-0775-8 PMID: 21279664

38. Millbourn D, Israelsson LA. Wound complications and stitch length. Hernia. 2004; 8: 39–41. PMID: 13680306

39. Israelsson LA. The surgeon as a risk factor for complications of midline incisions. Eur J Surg. 1998; 164: 353–9. PMID: 9667469

40. Fassiadis N, Roidl M, Hennig M, South LM, Andrews SM. Randomized clinical trial of vertical or transverse laparotomy for abdominal aortic aneurysm repair. Br J Surg. 2005; 92: 1208–11. PMID: 16175532

41. Sugerman HJ, Kellum JM Jr., Reines HD, DeMaria EJ, Newsome HH, Lowry JW. Greater risk of incisional hernia with morbidly obese than steroid-dependent patients and low recurrence with prefascial polypropylene mesh. Am J Surg. 1996; 171: 80–4. PMID: 8554156

42. Takagi H, Sugimoto M, Kato T, Matsuno Y, Uremoto T. Prospective, randomized evaluation of midline fascial closure in gastric bariatric operations. Br J Surg. 1996; 83: 328–31. PMID: 8873523
52. Corman ML, Veidenheimer MC, Collier JA. Controlled clinical trial of three suture materials for abdominal wall closure after bowel operations. Am J Surg. 1981; 141: 510–13. PMID: 6452825
53. Cameron AE, Parker CJ, Field ES, Gray RC, Wyatt AP. A randomised comparison of polydioxanone (PDS) and polypropylene (Prolene) for abdominal wound closure. Ann R Coll Surg Engl. 1987; 69: 113–5. PMID: 3111339
54. Carlson MA, Condon RE. Polyglyconate (Maxon) versus nylon suture in midline abdominal incision closure: a prospective randomized trial. Am Surg. 1995; 61: 980–3. PMID: 7486431
55. Krukowski ZH, Cusick EL, Engeset J, Matheson NA. Polydioxanone or polypropylene for closure of midline abdominal incisions: a prospective comparative clinical trial. Br J Surg. 1987; 74: 828–30. PMID: 3117165
56. McNeil PM, Sugerman HJ. Continuous absorbable vs interrupted nonabsorbable fascial closure. A prospective, randomized comparison. Arch Surg. 1986; 121: 821–3. PMID: 3013123
57. Israelsson LA, Jonsson T. Closure of midline laparotomy incisions with polydioxanone and nylon: the importance of suture technique. Br J Surg. 1994; 81: 1606–8. PMID: 7827883
58. Rucinski J, Margolis M, Panagopoulos G, Wise L. Closure of the abdominal midline fascia: meta-analysis delineates the optimal technique. Am Surg. 2001; 67: 421–6. PMID: 11379640
59. Sajid MS, Parampalli U, Baig MK, McFall MR. A systematic review on the effectiveness of slowly-absorbable versus non-absorbable sutures for abdominal fascial closure following laparotomy. Int J Surg. 2011; 9: 615–25. doi: 10.1016/j.ijsu.2011.09.006 PMID: 22061310
60. Muyssoms FE, Antoniou SA, Bury K, Campanelli G, Conze J, Cucurullo D, et al. European Hernia Society guidelines on the closure of abdominal wall incisions. Hernia. 2015; (In Press).
61. Sivam NS, Suresh S, Hadke MS, Kate V, Ananthakrishnan N. Results of the Smead-Jones technique of closure of vertical midline incisions for emergency laparotomies—a prospective study of 403 patients. Trop Gastroenterol. 1993; 16: 113–6. PMID: 8554963
62. Shukla VK, Gupta A, Singh H, Pandey M, Gautam A. Cardiff repair of incisional hernia: a university hospital experience. Eur J Surg. 1998; 164: 271–4. PMID: 9641368
63. Guillou PJ, Hall TJ, Donaldson DR, Broughton AC, Brennan TG. Vertical abdominal incisions—a choice? Br J Surg. 1980; 67: 395–9. PMID: 6992914
64. Bucknall TE, Cox PJ, Ellis H. Burst abdomen and incisional hernia: a prospective study of 1129 major laparotomies. Br Med J. 1982; 284: 931–3.
65. Shepherd JH, Cavanagh D, Riggs D, Prphat A, Wernsiwski BJ. Abdominal wound closure using a nonabsorbable single-layer technique. Obstet Gynecol. 1983; 61: 248–52. PMID: 6337356
66. Cox P, Ausobsky J, Ellis H, Pollock A. Towards no incisional hernias: lateral paramedian versus midline incisions. J R Soc Med. 1986; 79: 711–2. PMID: 3543347
67. Playforth MJ, Sauven PD, Evans M, Pollock AV. The prediction of incisional hernias by radio-opaque markers. Ann R Coll Surg Engl. 1986; 68: 82–4. PMID: 3954314
68. Paes TR, Stoker DL, Ng T, Morecroft J. Circumumbilical versus transumbilical abdominal incision. Br J Surg. 1987; 74: 822–4. PMID: 3311285
69. Schoetz DJ Jr., Collier JA, Veidenheimer MC. Closure of abdominal wounds with polydioxanone. A prospective study. Arch Surg. 1988; 123: 72–4. PMID: 2962561
70. Khakim M, Bashankavae B, Persson B, Cera S, Sands D, Weiss E, et al. Laparoscopic versus open proctectomy for rectal cancer: patients' outcome and oncologic adequacy. Surg Laparosc Endosc Percutan Tech. 2009; 19: 118–22. doi: 10.1097/SLE.0b013e318181a665 PMID: 19390277
71. Trimbos JB, Smit IB, Holm JP, Hermans J. A randomized clinical trial comparing two methods of fascial closure following midline laparotomy. Arch Surg. 1992; 127: 1232–4. PMID: 1417492
72. Gislason H, Gronbech JE, Soreide O. Burst abdomen and incisional hernia after major gastrointestinal operations—comparison of three closure techniques. Eur J Surg. 1995; 161: 349–54. PMID: 7662780
73. Colombo M, Maggioni A, Parma G, Scalambrino S, Milani R. A randomized comparison of continuous versus interrupted mass closure of midline incisions in patients with gynecologic cancer. Obstet Gynecol. 1997; 89: 684–9. PMID: 9166301
74. Hsiao WC, Young KC, Wang ST, Lin PW. Incisional hernia after laparotomy: prospective randomized comparison between early-absorbable and late-absorbable suture materials. World J Surg. 2000; 24: 747–51. PMID: 10773130
75. Musella M, Milone F, Chello M, Angelini P, Jovino R. Magnetic resonance imaging and abdominal wall hernias in aortic surgery. J Am Coll Surg. 2001; 193: 392–5. PMID: 11584967
76. Lai IR, Lee YC, Lee WJ, Yuan RH. Comparison of open and laparoscopic antireflux surgery for the treatment of gastroesophageal reflux disease in Taiwanese. J Formos Med Assoc. 2002; 101: 547–51. PMID: 12440084
77. 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: 294–7. PMID: 12447555

78. Winslow ER, Fleshman JW, Bimbam EH, Brunt LM. Wound complications of laparoscopic vs open colectomy. Surg Endosc. 2002; 16: 1420–5. PMID: 12085142

79. Lim SW, Huh JW, Kim YJ, Kim HR. Vertical transumbilical incision versus left lower transverse incision for specimen retrieval during laparoscopic colorectal surgery. Tech Coloproctol. 2013; 17: 59–65. doi: 10.1007/s10151-012-0883-9 PMID: 22936591

80. Raffetto JD, Cheung Y, Fisher JB, Cantelmo NL, Watkins MT, Lamorte WW, et al. Incision and abdominal wall hernias in patients with aneurysm or occlusive aortic disease. J Vasc Surg. 2003; 37: 1150–4. PMID: 12764257

81. Liapis CD, Dimitroulis DA, Kakisis JD, Nikolaou AN, Skandalakis P, Daskalopoulos M, et al. Incidence of incisional hernias in patients operated on for aneurysm or occlusive disease. Am Surg. 2004; 70: 550–2. PMID: 15212414

82. Marwah S, Marwah N, Singh M, Kapoor A, Karwasra RK. Addition of rectus sheath relaxation incisions to emergency midline laparotomy for peritonitis to prevent fascial dehiscence. World J Surg. 2005; 29: 235–9. PMID: 16886335

83. Ihedioha U, Mackay G, Leung E, Molloy RG, O'Dwyer PJ. Laparoscopic colorectal resection does not reduce incisional hernia rates when compared with open colorectal surgery. Surg Endosc. 2008; 22: 689–92. PMID: 17623241

84. Laurent C, Leblanc F, Bretagnol F, Capdepont M, Rullier E. Long-term wound advantages of the laparoscopic approach in rectal cancer. Br J Surg. 2008; 95: 903–8. doi: 10.1002/bjs.6134 PMID: 18551506

85. Singh R, Omiccioli A, Hegge S, McKinley C. Does the extraction-site location in laparoscopic colorectal surgery have an impact on incisional hernia rates? Surg Endosc. 2008; 22: 2596–600. doi: 10.1007/s00464-008-9845-8 PMID: 18347858

86. Togo S, Nagano Y, Masumoto C, Takakura H, Matsuo K, Takeda K, et al. Outcome of and risk factors for incisional hernia after partial hepatectomy. J Gastrointest Surg. 2008; 12: 1115–20. doi: 10.1007/s11605-008-0469-7 PMID: 19474689

87. Seiler CM, Deckert A, Diener MK, Knaebel HP, Weigand MA, Victor N, et al. Midline versus transverse incision in major abdominal surgery: a randomized, double-blind equivalence trial (POVATI). Ann Surg. 2009; 249: 913–20. doi: 10.1097/SLA.0b013e3181a77c92 PMID: 19474689

88. Veljkovic R, Protic M, Gluhovic A, Potic Z, Milosevic Z, Z stojadinovic A. Prospective Clinical Trial of Factors Predicting the Early Development of Incisional Hernia after Midline Laparotomy. J Am Coll Surgeons. 2010; 210: 210–9.

89. Al-Dahamsheh MH. Incisional Hernia of Elective Midline Caesarean Section: Incidence and Risk Factors. Bangladesh J Obstet Gynaecol. 2013; 25: 9–14.

90. Berretta R, Rolla M, Patrelli TS, Piantelli G, Merisio C, Melpignano M, et al. Randomised prospective study of abdominal wall closure in patients with gynaecological cancer. Aust N Z J Obstet Gynaecol. 2010; 50: 391–6. doi: 10.1111/j.1479-828X.2010.01194.x PMID: 20716270

91. Skipworth JR, Khan Y, Motson RW, Arulampalam TH, Engledow AH. Incisional hernia rates following laparoscopic colorectal resection. Int J Surg. 2010; 8: 470–3. doi: 10.1016/j.ijsu.2010.06.008 PMID: 20603232

92. DeSouza A, Domajnko B, Park J, Marecik S, Prasad L, Abcarian H. Incisional hernia, midline versus low transverse incision: what is the ideal incision for specimen extraction and hand-assisted laparoscopy? Surg Endosc. 2011; 25: 1031–6. doi: 10.1007/s00464-010-1309-2 PMID: 20737171

93. Justinger C, Slotta JE, Schilling MK. Incisional hernia after abdominal closure with slowly absorbable versus fast absorbable, antibacterial-coated sutures. Surgery. 2012; 151: 398–403. doi: 10.1016/j.surg.2011.08.004 PMID: 22088813
97. Klarenbeek BR, Bergamaschi R, Veenhof AA, van der Peet DL, van den Broek WT, de Lange ES, et al. Laparoscopic versus open sigmoid resection for diverticular disease: follow-up assessment of the randomized control Sigma trial. Surg Endosc. 2011; 25: 1121–6. doi:10.1007/s00464-010-1327-0 PMID: 20872022

98. 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: 1651–5. doi:10.1007/s00268-011-1131-6 PMID: 21547421

99. Salayta WM, Al Dahamsheh H. Incisional hernia after elective midline caesarean section: Incidence and risk factors. Rawal Med J. 2011; 36: 214–7.

100. Albertsmeier M, Seiler CM, Fischer L, Baumann P, Husing J, Seidlmayer C, et al. Evaluation of the safety and efficacy of MonoMax(R) suture material for abdominal wall closure after primary midline laparotomy-a controlled prospective multicentre trial: ISSAAC. Langenbecks Arch Surg. 2012; 397: 363–71. doi:10.1007/s00423-011-0884-6 PMID: 22183105

101. Lee L, Mappin-Kasirer B, Sender Liberman A, Stein B, Charlebois P, Vassiliou M, et al. High incidence of symptomatic incisional hernia after midline extraction in laparoscopic colon resection. Surg Endosc. 2012; 26: 3180–5. doi:10.1007/s00464-012-2311-7 PMID: 22580878