# Immediate Reconstruction of Complex Spinal Wounds Is Associated with Increased Hardware Retention and Fewer Wound-related Complications: A Systematic Review and Meta-analysis

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**Background:** Patients undergoing surgeries involving extensive posterior spine instrumentation and fusion often have multiple risk factors for wound healing complications. We performed a systematic review and meta-analysis of the available evidence on immediate (proactive/prophylactic) and delayed (reactive) spinal wound reconstruction. We hypothesized that immediate soft-tissue reconstruction of extensive spinal wounds would be associated with fewer postoperative surgical-site complications than delayed reconstruction.

**Methods:** In accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, a PubMed database search was performed to identify English-language, human-subject literature published between 2003 and 2018. Data were summarized, and the pooled prevalence of various wound complications was calculated, weighted by study size, using the generic inverse variance method. A subgroup analysis of all studies with a comparison group (Oxford Centre for Evidence-based Medicine level 3 or better) was performed, and Forest plots were created.

**Results:** The database search yielded 16 articles including 828 patients; 428 (51.7%) received an immediate spinal wound reconstruction and 400 (48.3%) had a delayed reconstruction. Spinal neoplasm was the most common index diagnosis. Paraspinous muscle flap reconstruction was performed in the majority of cases. Pooled analysis of all studies revealed immediate reconstruction to be associated with decreased rates of overall wound complications (28.5% versus 18.8%), hardware loss (10.7% versus 1.8%), and wound infections (10.7% versus 7.6%) compared with delayed reconstruction.

**Conclusions:** Immediate soft-tissue reconstruction of high-risk spinal wounds is associated with fewer wound healing complications and increased hardware retention. *(Plast Reconstr Surg Glob Open 2019;7:e2076; doi: 10.1097/GOX.0000000000002076; Published online 22 January 2019.)*

## INTRODUCTION

Soft-tissue defects overlying the midline posterior trunk following surgery with extensive spinal instrumentation represent a challenging clinical scenario. Such wounds may occur following oncologic resection, spinal trauma, or congenital, or acquired deformity correction, among

**Disclosure:** *The authors have no financial interest to declare in relation to the content of this article. The Article Processing Charge was paid for by the authors.*

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other etiologies. This patient population is complex, frequently presenting with multiple comorbidities known to negatively impact wound healing, such as obesity, previous spine surgery, the presence of spinal hardware, tobacco use, malnutrition, and preoperative radiation therapy.[1–23] Contemporary spine surgery techniques often require significant stripping of soft tissue from bone, dead space creation, and placement of extensive spinal instrumentation—factors that all potentially compromise postoperative healing. In general, if a wound healing complication does occur, the patient will require serial debridements and possible hardware removal or replacement, followed by soft-tissue reconstruction with local flaps. Wound healing complications following spine surgery are associated with considerable morbidity, including a high risk of deformity, neural injury, cerebrospinal fluid (CSF) leak, and paralysis.[2,3] Considering the potentially devastating effect of a wound healing complication after spine surgery, spine surgeons and plastic surgeons have developed a number of practices intended to optimize healing in these unique scenarios.[21–25]

Several authors have demonstrated encouraging results by adopting a proactive, rather than reactive, approach to spinal wounds, combining the initial spine surgery with an immediate prophylactic soft-tissue reconstruction in patients deemed at high risk for wound healing complications, such as those who have undergone radiation therapy or spine surgery previously or who have diabetes or extensive spinal hardware.[4–13] Other authors prefer a reactive approach, performing a delayed soft-tissue reconstruction only in the event the patient develops a major postsurgical wound healing complication.[14–19] The available literature on this subject is contradictory, with the majority of studies being retrospective case series and case reports that lack a control cohort, and there is no consensus on whether a proactive or reactive approach to oncologic spinal reconstruction results in lesser morbidity. Therefore, we have performed a systematic review and meta-analysis of the available evidence on soft-tissue reconstruction after spine surgery with the purpose of determining which approach is more appropriate. We hypothesized that immediate reconstruction of high-risk spinal wounds would be associated with fewer surgical-site complications and a higher hardware retention rate when compared with delayed reconstruction.

## METHODS

### Search Strategy

A systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (Fig. 1). The literature review of the PubMed database was conducted by 2 independent reviewers using the keywords spine, spinal, vertebra, vertebral, posterior trunk, flap, muscle flap, fasciocutaneous flap, soft-tissue reconstruction, and reconstruction; Boolean logical operators AND or OR were used in combination with the search terms. An immediate reconstruction was defined as any reconstruction performed prophylactically, at the time of the index spine surgery; a delayed reconstruction was defined as any soft-tissue reconstruction performed second-

arily, during a separate surgery, to treat a wound healing complication that occurred after the index spine surgery.

### Eligibility Criteria and Study Selection

The inclusion criteria consisted of any trial or case series reporting clearly quantifiable wound outcomes associated with either immediate or delayed soft-tissue reconstruction after an index spine surgery in the English-language, human-subject literature published between 2003 and 2018. Articles published before 2003 were excluded because of the significant improvements in instrumentation and technique developed since then. Case reports, systematic reviews, articles by the same author with identical data, meta-analyses, basic science studies, cadaver studies, editorials, and commentaries were also excluded. When summarizing results, only wound complications associated with the surgically created spine wound were included.

### Data Extraction Process

The following data were recorded for each article: authors; date of publication; number of patients; mean patient age; timing of reconstruction (immediate versus delayed); overall wound complication rate; and rates of wound infection, seroma, hematoma, wound dehiscence, partial flap loss, total flap loss, and hardware loss. The type and number of flaps and the indication for the initial index spine surgery were recorded if reported in the article. Each study's quality was assessed according to the Oxford Centre for Evidence-based Medicine (OCEBM) guidelines. Two independent reviewers extracted data; discrepancies were reviewed and discussed until consensus was accomplished.

### Statistical Analysis

Data were summarized, and the pooled prevalence of each complication was calculated, weighted by study size, using the generic inverse variance method (Review Manager 5; The Cochrane Collaboration, Copenhagen, Denmark). Interstudy heterogeneity was quantified using the $I^2$ statistic, with $I^2$ less than 50% regarded as low heterogeneity, 50–75% as moderate heterogeneity, and >75% as high heterogeneity. Values of $P < 0.05$ indicated a significant difference between groups (IBM SPSS Version 25, Armonk, N.Y.).

The presence of a comparison group (ie, OCEBM level of evidence III or better) allowed for more rigorous analysis. For these studies, Forest plots were created. Variables were pooled and modeled by the Peto method and compared using odds ratios with 95% confidence intervals. Values of $P < 0.05$ indicated a significant difference between groups. The Peters test was used to detect publication bias when $I^2$ was greater than 50%; $P > 0.05$ indicated no publication bias.

## RESULTS

### Search Results

We identified 205 unique articles with our database searches. After applying our exclusion criteria and screening for relevance, 16 articles remained (Fig. 1). All studies were retrospective case series, evenly split between
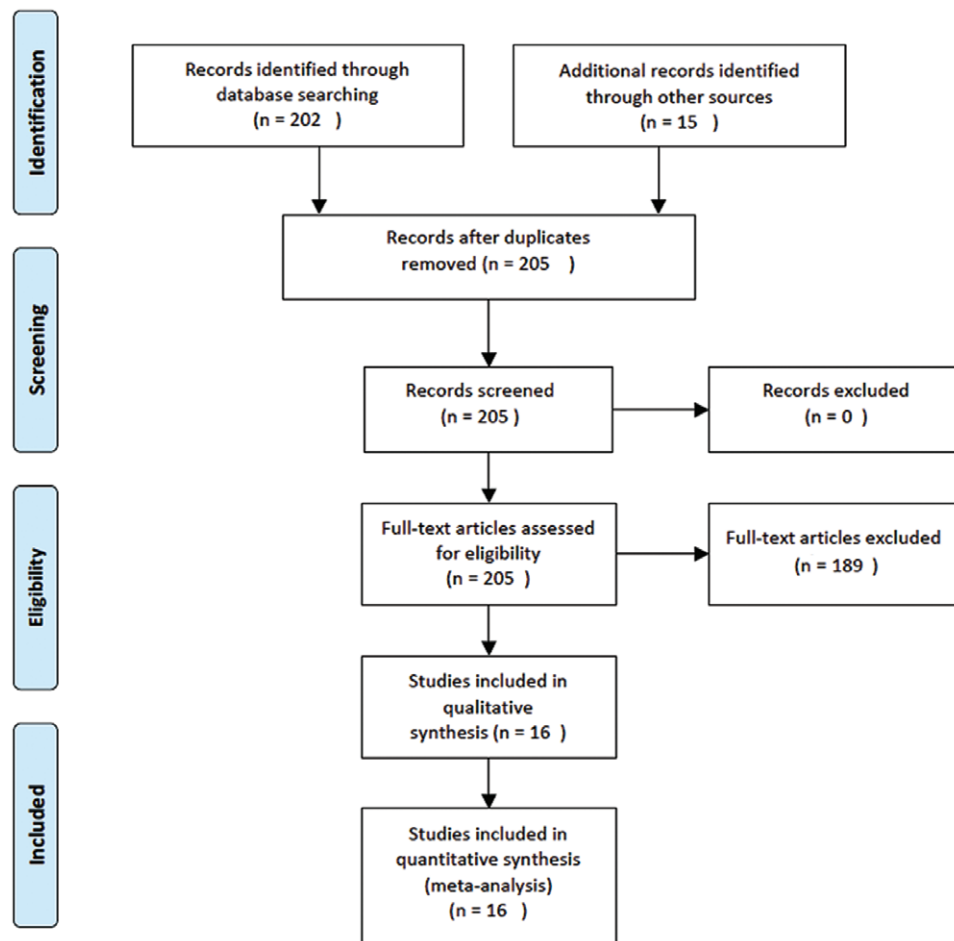
**Fig. 1.** PRISMA data collection flow chart. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses

OCEBM level IV (8 studies) and level III (8 studies). There were no level II or level I studies. The 16 articles included 828 patients, in which 428 (51.7%) received an immediate spinal wound reconstruction and 400 (48.3%) had a delayed reconstruction. The mean age was $51.5 \pm 4.1$ years in the immediate reconstruction group and $53.4 \pm 4.3$ years in the delayed group ($P = 0.87$). Studies describing immediate reconstruction reported a mean follow-up of 26.2 months (range = 8.8–110.5 months) compared with 22.4 months (4.1–94.6 months) for studies detailing delayed reconstructions (Table 1).

**Indications for Index Spine Surgery**

All patients underwent soft-tissue reconstruction after spine surgery for an index diagnosis, the most common of which for both groups was neoplastic disease (immediate = 73%; delayed = 47%). Spine surgery related to a degenerative musculoskeletal condition such as disk disease or spinal stenosis was more common among delayed reconstruction patients (30%) than among immediate reconstruction patients (1%). Otherwise, the surgical indication distributions were fairly similar between the 2 groups (Fig. 2).

**Predictors of Complications Requiring Delayed Soft-tissue Reconstruction**

In all instances, patients underwent delayed soft-tissue reconstruction after developing a wound healing complication after an index spine surgery. None of the articles included in this systematic review were designed to identify risk factors for poor healing following spine surgery; however, most articles did discuss such potential variables. Previous spine surgery was the most consistently identified risk factor.[5–17] Other frequently cited risk factors included radiation therapy, obesity, CSF fistula, and the presence of hardware.[5,7,10,14–16] In the delayed reconstruction cohort, Dolan et al.[10] identified an increased incidence of complications among patients presenting with previous radiation therapy (57% versus 10%), previous spine surgery with instrumentation (50% versus 13%), obesity (53% versus 12%), or tobacco use (68% versus 21%). In comparing immediate and delayed reconstruction patients, Chang et al.[7] identified an increased incidence of complications in delayed reconstruction patients with previous radiation therapy (58% versus 32%), previous spine surgery (63% versus 36%), and spinal instrumentation (46% versus 23%). Other articles included in this review cited the following additional risk factors for wound healing com-

**Table 1. Studies Detailing Immediate and Delayed Reconstructions**

| Study | Year | Mean Follow-up, mo (range) | Level of Evidence | n | Overall Wound Complications, n (%) | Infection, n (%) | Seroma, n (%) | Hematoma, n (%) | Hardware Loss/Exposure, n (%) | Wound Dehiscence, n (%) | Flap Loss, n (%) | Partial Flap Loss, n (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Immediate** | | | | | | | | | | | | |
| Devulapalli et al.[8] | 2017 | 14 (0–197)* | 3 | 224 | 54 (24.1) | 42 (18.7) | 13 (5.8) | 1 (0.45) | 2 (0.9) | 29 (12.9) | 5 (2.2) | 8 (3.6) |
| Sambri et al.[13] | 2017 | NR | 3 | 1 | 0 (0) | 0 (0) | 0 (0) | 1 (25) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Cohen et al.[12] | 2016 | NR (2–60)* | 3 | 50 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Dolan et al.[10] | 2016 | 55.5 (13–128)* | 3 | 35 | 10 (28.6) | 4 (11.4) | 0 (0) | 2 (5.7) | 0 (0) | 3 (8.6) | 0 (0) | 2 (5.7) |
| Garvey et al.[6] | 2010 | 9.7 (1–55.3) | 4 | 52 | 6 (12) | 8 (15) | 13 (25) | 2 (3.8) | 2 (3.8) | 2 (3.8) | 0 (0) | 0 (0) |
| O'Shaughnessy et al.[4] | 2007 | 53 (36–115) | 4 | 5 | 1 (20) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (20) | 0 (0) | 0 (0) |
| Chang et al.[7] | 2007 | 21 (1–108)* | 3 | 44 | 14 (32) | 1 (2.3) | 2 (4.5) | 2 (4.5) | 2 (4.5) | 5 (11.3) | 2 (4.5) | 5 (11.3) |
| Dumanian et al.[9] | 2003 | "At least 24 months" | 3 | 7 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Chun et al.[11] | 2003 | NR | 3 | 3 | 2 (67) | 0 (0) | 2 (67) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Saint-Cyr et al.[5] | 2003 | 5.9* | 3 | 7 | 2 (28.6) | 0 (0) | 1 (14.3) | 1 (14.3) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Total | | | | 428 | 89 | 55 | 31 | 8 | 5 | 40 | 7 | 15 |
| Pooled prevalence† | | | | | 18.8% | 7.6% | 7.7% | 4.1% | 1.8% | 7.3% | 2.0% | 3.5% |
| Range | | | | | 0–67% | 0–19% | 0–67% | 0–25% | 0–4.5% | 0–20% | 0–4.5% | 0–11.3% |
| I² | | | | | 81% | 73% | 75% | 58% | 0% | 53% | 0% | 27% |
| P‡ | | | | | <0.001 | <0.001 | <0.001 | 0.0100 | 0.69 | 0.02 | 0.79 | 0.19 |
| **Delayed** | | | | | | | | | | | | |
| Devulapalli et al.[8] | 2017 | 14 (0–197)* | 3 | 65 | 10 (15.3) | 11 (16.9) | 2 (3.1) | 0 (0) | 3 (4.6) | 8 (12.3) | 1 (1.5) | 2 (3.1) |
| Sambri et al.[13] | 2017 | NR | 3 | 4 | 1 (25) | 0 (0) | 0 (0) | 1 (25) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Cohen et al.[12] | 2016 | NR (2–60)* | 3 | 52 | 6 (11.5) | 6 (11.5) | 0 (0) | 0 (0) | 2 (3.8) | 5 (9.6) | 0 (0) | 0 (0) |
| Dolan et al.[10] | 2016 | 55.5 (13–128)* | 3 | 20 | 12 (60) | 6 (30) | 0 (0) | 3 (15) | 2 (10) | 5 (25) | 3 (15) | 1 (5) |
| de Weerd et al.[18] | 2015 | 65 (7–106) | 4 | 9 | 2 (20) | 1 (10) | 0 (0) | 0 (0) | 1 (10) | 1 (10) | 0 (0) | 1 (10) |
| Mericli et al. | 2011 | 1.1 | 4 | 14 | 2 (14) | 2 (14) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Mericli et al. | 2010 | 4 | 4 | 92 | 23 (25) | 12 (25) | 11 (12) | 1 (1) | 5 (5.5) | 1 (1) | 0 (0) | 0 (0) |
| Chang et al.[7] | 2007 | 21 (1–108)* | 3 | 48 | 15 (31) | 3 (6) | 8 (17) | 0 (0) | 9 (18.7) | 5 (10) | 1 (2) | 8 (17) |
| Hultman et al.[15] | 2006 | 6.6 (1–29) | 4 | 25 | 14 (56) | 3 (12) | 2 (8) | 0 (0) | 5 (20) | 1 (4) | 0 (0) | 0 (0) |
| Vitaz et al.[17] | 2004 | NR | 4 | 37 | 5 (13.5) | 0 (0) | 2 (5.4) | 0 (0) | 2 (5.4) | 1 (2.7) | 0 (0) | 0 (0) |
| Meiners et al.[19] | 2003 | 27.4 (8–45) | 4 | 15 | 7 (15) | 0 (0) | 0 (0) | 3 (21) | 10 (71) | 3 (14) | 0 (0) | 0 (0) |
| Dumanian et al.[9] | 2003 | "At least 24 months" | 3 | 15 | 5 (33) | 1 (6.67) | 3 (20) | 1 (6.67) | 0 (0) | 1 (6.67) | 1 (6.67) | 0 (0) |
| Chun et al.[11] | 2003 | NR | 3 | 2 | 1 (50) | 0 (0) | 1 (50) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Saint-Cyr et al.[5] | 2003 | 5.9* | 3 | 2 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Total | | | | 400 | 103 | 45 | 29 | 9 | 39 | 31 | 6 | 12 |
| Pooled prevalence† | | | | | 28.5% | 10.7% | 6.5% | 2.9% | 10.7% | 8.6% | 1.8% | 3.0% |
| Range | | | | | 0–60% | 0–30% | 0–50% | 0–25% | 0–71% | 0–25% | 0–15% | 0–17% |
| I² | | | | | 68% | 43% | 56% | 47% | 69% | 45% | 7% | 49% |
| P‡ | | | | | 0.001 | 0.04 | 0.005 | 0.02 | 0.001 | 0.03 | 0.37 | 0.02 |

*Same length of follow-up reported for both immediate and delayed groups.
†Weighted by study size.
‡P referring to I² value and data heterogeneity. P < 0.05 = significant heterogeneity.

plications following spine surgery: diabetes, neoadjuvant chemotherapy, chronic steroid use, malnutrition, traumatic spine injury, and lumbosacral location.[14,15]
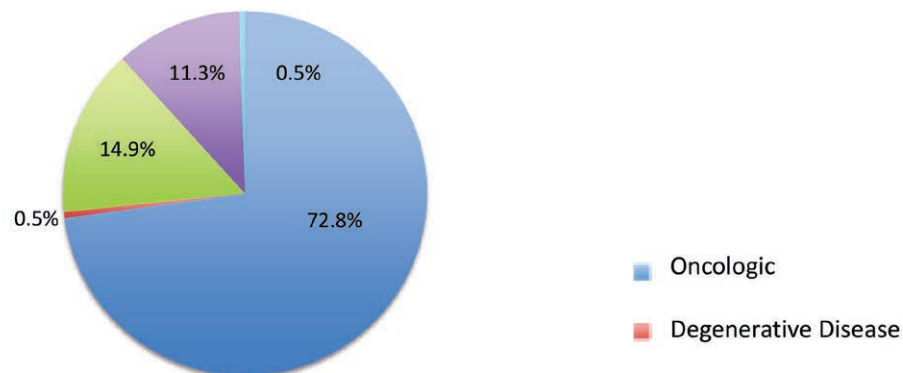
**Indications for Delayed Soft-tissue Reconstruction**

Infection, CSF fistula, and wound dehiscence were the most common indications cited as reasons for a delayed soft-tissue reconstruction. Vitaz et al.[17] reported a mean of 45.2 days between the index spine surgery and the development of a wound complication in patients with degenerative musculoskeletal conditions versus a mean of 37 days in oncologic patients. Other studies evaluating outcomes for delayed spine reconstruction reported mean durations of 1–7 months between the index spine surgery and definitive reconstruction.[9,13,15,19] Most authors reported that 1–3 operative debridements were performed before definitive reconstruction; the temporizing procedures included provisional skin closure, conventional dressing changes, and negative-pressure wound dressing.[9,10,12,15,17,18] Several

authors stated that, in cases of dehiscence or infection, intraoperative examination during debridement yielded the most useful predictive information regarding the patient's candidacy for a delayed reconstruction. As stated by Mericli et al.,[16] patients were considered for paraspinous muscle flap reconstruction when there was "…no improvement in healing and/or wound appearance after culture-directed antibiotics, in the presence of exposed bone or hardware, or in situations of deep tracking or drainage during intraoperative examination." Regarding CSF leaks, wound revision was only considered after exhausting all conservative management strategies, such as bed rest, a lumbar drain, and/or an externalized ventricular drain.[5,7,9]

**Indications for Immediate Soft-tissue Reconstruction**

Chang et al.[7] compared immediate and delayed oncologic spinal wound reconstructions and identified previous spine surgery, the presence of instrumentation, and a lumbar or cervical location as predictors of postoperative

## Index Spine Pathology– Immediate Reconstruction
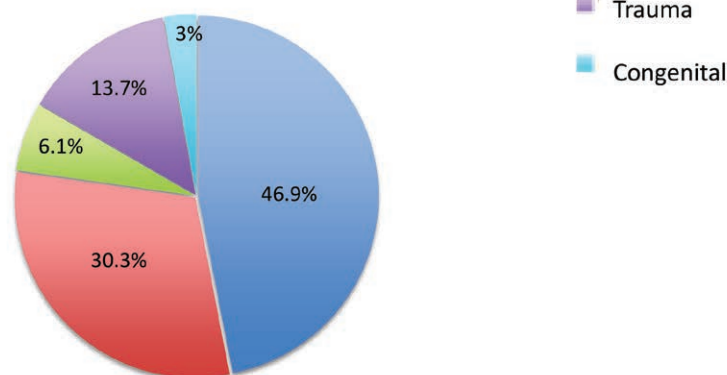


## Index Spine Pathology– Delayed Reconstruction



**Fig. 2.** Pie charts illustrating index spine pathology for patients undergoing immediate and delayed soft-tissue reconstruction.

complications and thus indications for immediate reconstruction. Patients who had prophylactic soft-tissue flap coverage of an instrumented spine wound experienced a significantly lower incidence of major wound complications requiring additional surgery compared with patients whose wounds were closed primarily (20% versus 45%; $P$ = 0.018).[7] Patients with previous spine surgery who had proactive, immediate soft-tissue reconstruction also had significantly fewer overall complications compared with patients with a history of spine surgery who did not have an immediate reconstruction (0% versus 21%; $P$ = 0.002). In a continuation of Chang's study, Garvey et al.[6] reviewed their long-term outcomes after immediate, prophylactic spinal wound reconstruction in high-risk oncologic patients. The authors cite a reduction in the rate of major wound complications from 38% to 12% after adopting a more proactive strategy and providing immediate reconstruction to patients with one or more of the following comorbidities: diabetes, cardiovascular disease, neoadjuvant chemotherapy, previous radiation therapy, smoking, prior spine surgery, or instrumentation. Both Dumanian et al.[9] and O'Shaughnessy et al.[4] set broader indications for immediate soft-tissue reconstruction than had been suggested by Chang and Garvey, offering immediate reconstruction to any patient presenting with either

a prior spine infection or a neoplastic process. Saint-Cyr et al.[5] studied the protective effect of immediate muscle flap reconstruction specifically for CSF leaks and recommended immediate reconstruction for patients possessing 3 or more of the following risk factors: previous radiation therapy, previous spine surgery, large resection defect (≥3 vertebral levels), an intradural lesion, or a dural repair.

**Reconstructive Technique and Flap Choice**

The paraspinous muscles were the most commonly used flaps in both immediate and delayed reconstructions (Fig. 3). The distribution of flaps between the delayed and immediate reconstruction cohorts was relatively similar, with the exception of there being more trapezius flaps employed for the immediate reconstructions (21% versus 9%). Five articles reported a total of 36 free flaps, all of which were performed in the immediate setting.[6–10]

**Overall Wound Complications**

Considering all included studies, there were more wound complications associated with delayed compared with immediate soft-tissue reconstruction (28.5% versus 18.8%; Table 1, Fig. 4). The delayed reconstruction studies were less heterogeneous ($I^2$ = 68%) than the immediate reconstruction studies ($I^2$ = 81%). When analyzing only

## Flap Type – Immediate Reconstruction
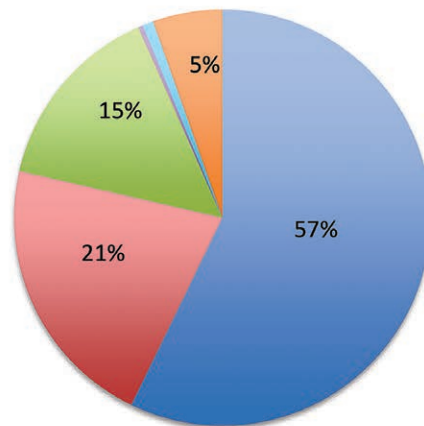


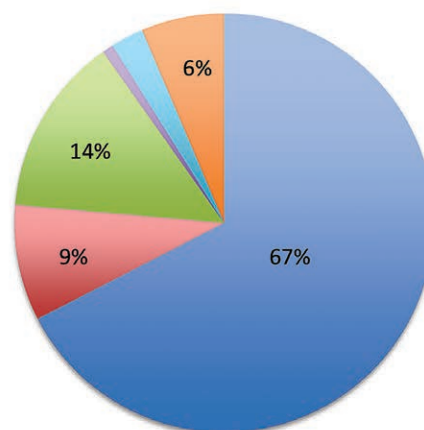## Flap Type – Delayed Reconstruction



**Fig. 3.** Pie charts illustrating the distribution of flaps utilized for immediate and delayed soft-tissue reconstruction

level III studies, there was moderate heterogeneity ($I^2 = 58\%$; $P = 0.02$) and a complication rate trending in favor of immediate reconstruction [odds ratio (OR) = 0.84; 95% CI = 0.54–1.3; $P = 0.43$; **see** Figure 5].

**Hardware Loss**

Considering all included studies, there were nearly 6-fold fewer instances of hardware loss/exposure associated with immediate soft-tissue reconstruction than with delayed reconstruction (10.7% versus 1.8%; Table 1, Fig. 4). The delayed reconstruction studies were heterogeneous ($I^2 = 69\%$), whereas those reporting immediate reconstructions were not ($I^2 = 0\%$). When analyzing only level III studies, there was low heterogeneity and no publication bias ($I^2 = 0\%$; $P = 0.98$), with data strongly favoring immediate reconstruction (OR = 0.18; 95 percent CI = 0.07–0.46; $P = 0.003$; **Supplemental Digital Content 1**).

**Wound Infection**

Considering all studies, there were more wound infections following delayed versus immediate reconstruc-

tion (10.7% versus 7.6%; Table 1, Fig. 4). The delayed reconstruction studies had low heterogeneity ($I^2 = 43\%$) compared with the immediate reconstruction studies ($I^2 = 73\%$). When analyzing only the level III studies, there was low-moderate heterogeneity, no publication bias ($I^2 = 51\%$; $P = 0.09$), and a statistically equivalent infection rate trending in favor of immediate reconstruction (OR = 0.64; 95% CI = 0.37–1.13; $P = 0.12$; Figure 5). The most common causative organisms identified in these infections were *Staphylococcus* species.[4,9,13–19] Other frequently reported pathogens included *Enterococcus, Escherichia coli, Pseudomonas*, and *Klebsiella*. In all studies in which a treatment was recommended, it was empiric, broad-spectrum antibiotics until culture-directed therapy could be initiated.[9,12,14–17]

**Seroma, Hematoma, and Wound Dehiscence**

Considering both level IV and level III studies, the incidences of minor wound healing complications such as seroma (6.5% versus 7.5%), hematoma (2.9% versus 4.1%), and wound dehiscence (8.6% versus 7.3%) were similar between delayed and immediate reconstruc-
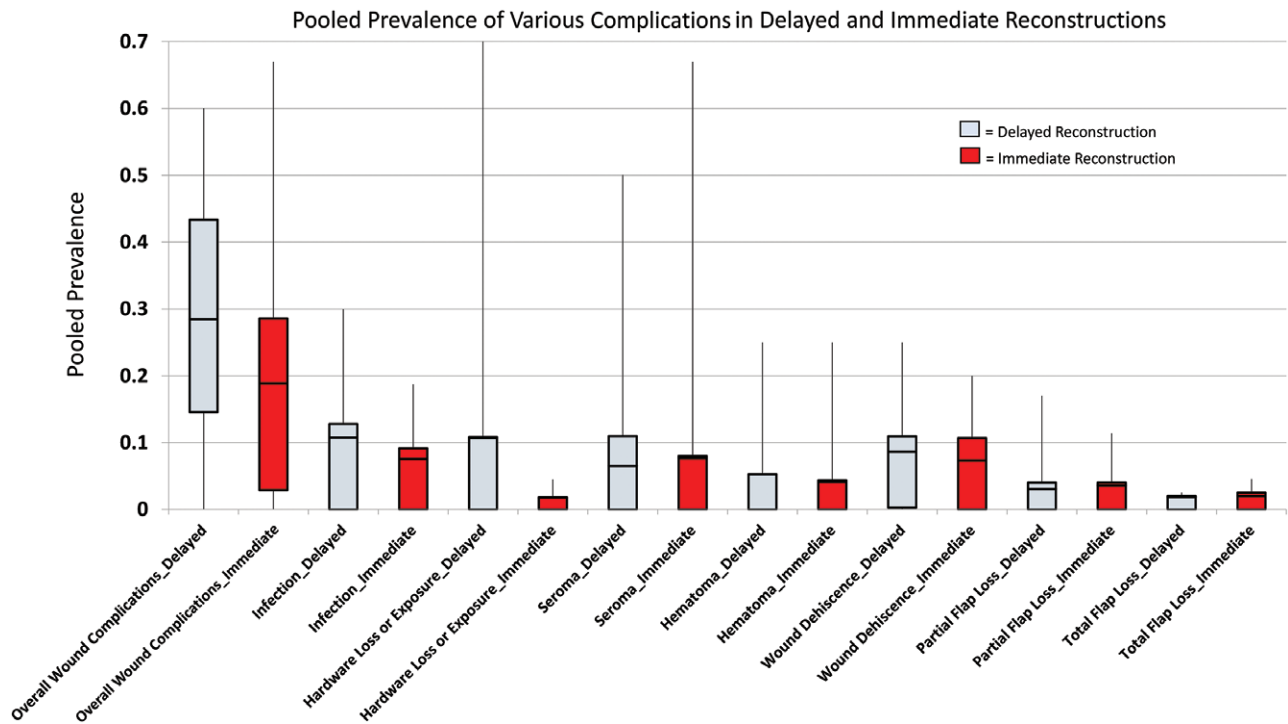
**Fig. 4.** Box and whiskers plot of the pooled prevalence of wound complications for all included studies. Boxes represent the 50th percentile for the prevalence of each complication; error bars illustrate the minimum and maximum values.

tions, respectively (Table 1, Fig. 2). Subgroup analyses of level III studies demonstrated similar findings, with data trending in favor of immediate reconstruction (**see** Figure 6, which displays a forest plots of all level 3 data detailing the incidence of minor wound healing complications in immediate versus delayed spinal wound reconstructions: A) Seroma B) Hematoma C) Wound dehiscence).

**Partial and Total Flap Loss**

Considering both level IV and level III studies, there was no difference in the rate of partial (3.0% versus 3.6%) or total (1.8% versus 2.0%) flap loss (Fig. 4). The data were relatively uniform, as evidenced by $I^2$ values ranging from 0% to 50% (Table 1). Subgroup analyses of level III

studies demonstrated similar findings (**see** Figure 7, which displays a forest plots of all level 3 data detailing the incidence of partial and total flap loss in immediate versus delayed spinal wound reconstructions: A) Partial Flap Loss B) Total Flap Loss).

**Predictors of Complications**

Several studies discussed risk factors for wound complications following soft-tissue reconstruction. Using multivariate logistic regression, Chang et al.[7] identified previous spine surgery to be an independent predictor associated with an almost 3 times higher risk of developing a postoperative complication (OR = 2.95, complication rate 20.8% versus 0%; $P = 0.002$). In contrast, immediate reconstruction was found to be an independent pro-
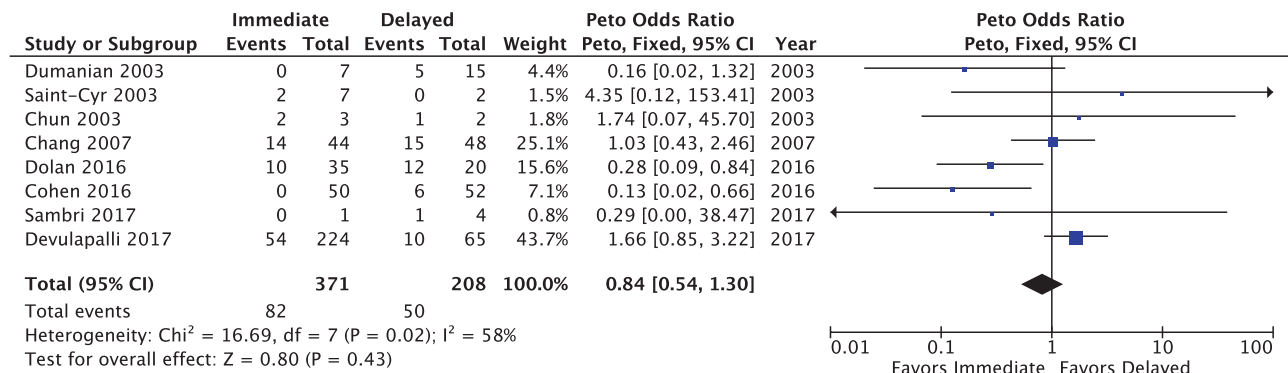


**Fig. 5.** Forest plot of overall wound complications for all level III studies. There is moderate interstudy heterogeneity and no publication bias ($I^2 = 58$ percent), and an odds ratio trending in favor of immediate reconstruction.
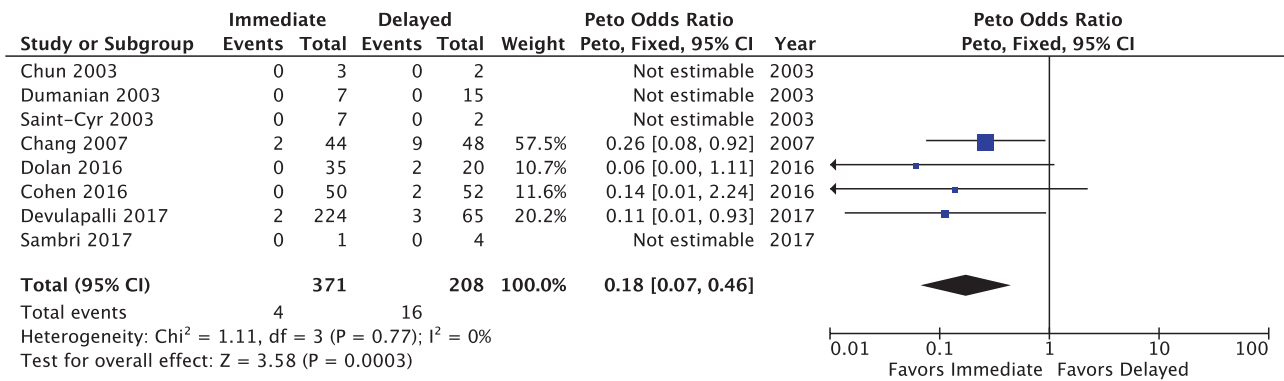
| Study or Subgroup | Immediate Events | Total | Delayed Events | Total | Weight | Peto Odds Ratio Peto, Fixed, 95% CI | Year | Peto Odds Ratio Peto, Fixed, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Chun 2003 | 0 | 3 | 0 | 2 | | Not estimable | 2003 | |
| Dumanian 2003 | 0 | 7 | 0 | 15 | | Not estimable | 2003 | |
| Saint–Cyr 2003 | 0 | 7 | 0 | 2 | | Not estimable | 2003 | |
| Chang 2007 | 2 | 44 | 9 | 48 | 57.5% | 0.26 [0.08, 0.92] | 2007 | |
| Dolan 2016 | 0 | 35 | 2 | 20 | 10.7% | 0.06 [0.00, 1.11] | 2016 | |
| Cohen 2016 | 0 | 50 | 2 | 52 | 11.6% | 0.14 [0.01, 2.24] | 2016 | |
| Devulapalli 2017 | 2 | 224 | 3 | 65 | 20.2% | 0.11 [0.01, 0.93] | 2017 | |
| Sambri 2017 | 0 | 1 | 0 | 4 | | Not estimable | 2017 | |
| | | | | | | | | |
| Total (95% CI) | | 371 | | 208 | 100.0% | 0.18 [0.07, 0.46] | | |
| Total events | 4 | | 16 | | | | | |

Heterogeneity: Chi$^2$ = 1.11, df = 3 (P = 0.77); I$^2$ = 0%
Test for overall effect: Z = 3.58 (P = 0.0003)

Favors Immediate   Favors Delayed

**Fig. 6.** Forest plot of hardware loss/exposure for all level III studies. There is low heterogeneity and no publication bias (I$^2$ = 0 percent; p = 0.77), with data strongly favoring immediate reconstruction (OR = 0.18; 95 percent CI = 0.07-0.46; p = 0.0003).
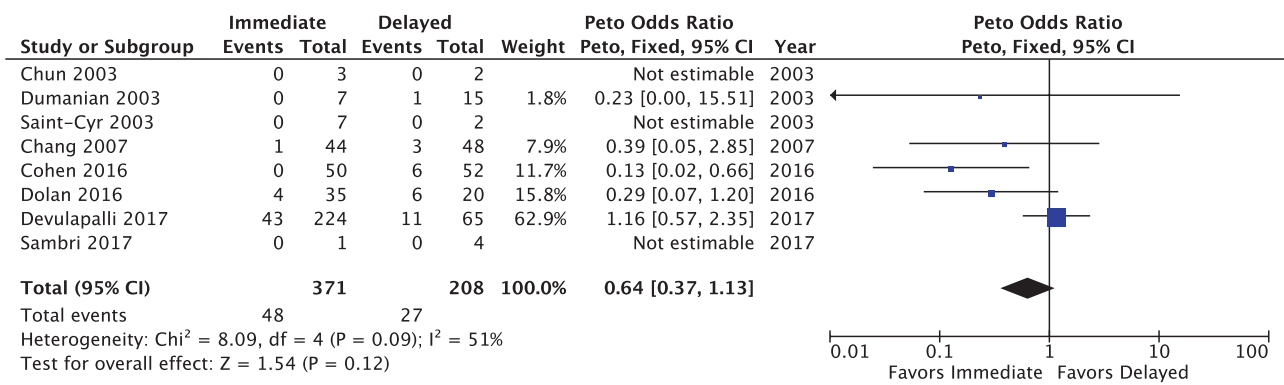
| Study or Subgroup | Immediate Events | Total | Delayed Events | Total | Weight | Peto Odds Ratio Peto, Fixed, 95% CI | Year | Peto Odds Ratio Peto, Fixed, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Chun 2003 | 0 | 3 | 0 | 2 | | Not estimable | 2003 | |
| Dumanian 2003 | 0 | 7 | 1 | 15 | 1.8% | 0.23 [0.00, 15.51] | 2003 | |
| Saint–Cyr 2003 | 0 | 7 | 0 | 2 | | Not estimable | 2003 | |
| Chang 2007 | 1 | 44 | 3 | 48 | 7.9% | 0.39 [0.05, 2.85] | 2007 | |
| Cohen 2016 | 0 | 50 | 6 | 52 | 11.7% | 0.13 [0.02, 0.66] | 2016 | |
| Dolan 2016 | 4 | 35 | 6 | 20 | 15.8% | 0.29 [0.07, 1.20] | 2016 | |
| Devulapalli 2017 | 43 | 224 | 11 | 65 | 62.9% | 1.16 [0.57, 2.35] | 2017 | |
| Sambri 2017 | 0 | 1 | 0 | 4 | | Not estimable | 2017 | |
| | | | | | | | | |
| Total (95% CI) | | 371 | | 208 | 100.0% | 0.64 [0.37, 1.13] | | |
| Total events | 48 | | 27 | | | | | |

Heterogeneity: Chi$^2$ = 8.09, df = 4 (P = 0.09); I$^2$ = 51%
Test for overall effect: Z = 1.54 (P = 0.12)

Favors Immediate   Favors Delayed

**Fig. 7.** Forest plot of wound infection for all level III studies. There is moderate heterogeneity and no publication bias (I$^2$ = 51 percent; p = 0.09), and an infection rate odds ratio trending in favor of immediate reconstruction.

tector for instrumented spine wounds, associated with a >50% decreased risk of developing a wound complication (OR = 0.56; 95% CI = 0.01–0.61; $P$ = 0.018). Examining only immediate reconstructions, Garvey et al.[6] found advanced age to be associated with wound complications ($P$ = 0.039). Studying only delayed reconstructions, Mericli et al.[14] found hardware removed before soft-tissue reconstruction (OR = 4.01; 95% CI = 1.3–12.4; $P$ = 0.02), a history of ≥2 spine surgeries (OR = 3.23; 95% CI = 1.17–8.9; $P$ = 0.001), a lumbar wound location (OR = 2.99; 95% CI = 1.19–7.49; $P$ = 0.01), and traumatic spine injury (OR = 2.19; 95% CI = 1.62–4.12; $P$ = 0.03) to be associated with postoperative complications. Looking at both immediate and delayed reconstructions, Devulapalli et al.[8] identified the following independent predictors of wound healing complications: free flap (OR = 8.97; 95% CI = 1.51–53.35; $P$ = 0.016), cardiovascular disease (OR = 3.25; 95% CI = 1.45–7.30; $P$ = 0.004), spine hardware (OR = 3.23; 95% CI = 1.29–8.10; $P$ = 0.012), female sex (OR = 2.81; 95% CI = 1.39–5.68; $P$ = 0.004), and spinal cord exposure (OR = 2.57; 95% CI = 1.06–6.19; $P$ = 0.036).

## DISCUSSION

The results of this systematic review and meta-analysis appear to support our initial hypothesis and suggest that delayed reconstruction results in significantly higher rates of overall wound complications, infection, and hardware failure compared with immediate reconstruction. Subgroup analysis of only the level III studies illustrated a similar trend: when immediate soft-tissue reconstruction was employed, hardware loss or exposure was significantly less common and overall wound complications and infections trended toward being less common.

In order for these results to be truly useful, it would be helpful to know which spine patients are at the greatest risk for developing a wound complication, and, therefore, which patients would derive the greatest utility from prophylactic, immediate soft-tissue wound reconstruction. Omesis et al.[21] reviewed their oncologic spine surgery experience in which all wounds were closed primarily by the spine surgeon, without flap advancement, and identified the following risk factors for wound healing complications: history of previous spine surgery ($P$ = 0.001), multi-level fusion ($P$ = 0.04), and greater than one comorbidity ($P$ < 0.001). Our systematic review of immediate and delayed spinal wound reconstructions yielded similar findings. A history of previous spine surgery was the most frequently identified risk factor for wound healing complications and was found not only to be associated with requiring a delayed soft-tissue reconstruction[7–10,12] but also to be indicative of the need for immediate soft-tissue reconstruction[6–10,12] and to be associated with the development of complications after

delayed soft-tissue reconstruction.[7,8,14,16] Other variables predictive of developing a wound complication following spine surgery significant enough to require soft-tissue reconstruction include radiation therapy, obesity, cardiovascular disease, smoking, and the presence of hardware.[5–17] Seventy-three percent of patients in the immediate group received spine surgery because of an index cancer diagnosis, whereas only 47% of patients in the delayed group carried an oncologic diagnosis. In contrast, only 1% of patients in the immediate reconstruction cohort received spine surgery to treat disc disease, compared with 30% of delayed reconstruction patients. This dichotomy can potentially be explained by the fact that oncologic patients have readily identifiable risk factors for wound healing complications (radiation, neoadjuvant chemotherapy, malnutrition, etc), prompting the spine surgeon to consider immediate reconstruction. However, the risk factors that a disc disease patient possesses are likely more occult and less overt, such as obesity, diabetes, coronary artery disease, chronic obstructive pulmonary disorder, collagen-vascular disease, and prior spine surgery. Although each of these individual, more commonplace risk factors, is potentially innocuous in isolation, when coexistent, likely produce an additive effect on surgical risk. Indeed, in the largest series of delayed spinal wound reconstructions, Mericli et al.[14] found that 97% of patients possessed at least 1 risk factor for poor wound healing and 86% had 2 or more. This observation emphasizes the importance of preoperative risk stratification as well as the utility of immediate reconstruction in patients deemed high risk.

Considering the numerous local and regional muscle flap options in the posterior trunk, most defects can be reconstructed with a pedicled flap. Options vary depending on the location of the defect, but in general, the paraspinous muscle flap is considered the first-line option. Coexistent spinal instrumentation and fusion renders the function of the paraspinous muscle (extension and vertebral stabilization) unnecessary, thus resulting in negligible donor-site morbidity compared with transfer of a more functionally important muscle, such as the latissimus. Some surgeons prefer trapezius flaps for cervical spine wounds; however, others have found success using paraspinous flaps.[6,16,17,20] In the thoracic spine, if the paraspinous muscles are not available, second-line options include the latissimus dorsi advancement flap (for the superior thoracic spine), the reverse turnover latissimus dorsi flap (for the inferior thoracic spine), and the omental flap.[4,6–13,19] In the lumbosacral spine, secondary options include the lumbar perforator flap, superior gluteal artery perforator flap, gluteal advancement flaps, reverse turnover latissimus dorsi flap, and omental flap.[4,6–13,15–17] Free tissue transfer is a last resort for the posterior trunk and is fraught with a high flap failure rate and high rate of complications. Indeed, Devulapalli et al.[8] identified a nearly 9-times greater risk of a complication when a free flap was used for reconstruction of a spinal defect. This is likely multifactorial and related to the paucity of recipient vessels, reliance on long vein grafts or arteriovenous loops for perfusion, and the more dependent location of the flap recipient site. Additionally, considering the numerous local and regional flap options associated with the posterior trunk, most patients receiving a free flap will have had numerous prior surgeries and failed reconstructions, possess multiple comorbidities, and have the most hostile of wounds, making these cases among the most complicated and high risk.

In the past, infection or exposure was thought to necessitate removal or replacement of spinal instrumentation. However, spinal instrumentation removal is associated with a high complication rate, including neurologic injury, paralysis, and CSF leakage, and should be avoided if possible.[2,3] Furthermore, at least one study has identified instrumentation removal as a risk factor for wound complications following soft-tissue reconstruction.[14] Our systematic review has identified the presence of spinal instrumentation as a major risk factor for developing a wound complication requiring a delayed soft-tissue reconstruction, as well as a risk factor for developing a wound complication following soft-tissue reconstruction. Because of this, most studies consider the presence of hardware to be an indication for immediate, prophylactic reconstruction in at-risk patients. Indeed, the most significant finding from our meta-analysis is the reduction in the incidence of hardware loss or exposure in patients undergoing immediate soft-tissue reconstruction (**Supplemental Digital Content 1**). However, it is important to note that a short segment of low-profile hardware certainly does not confer the same risk as high-profile hardware spanning multiple vertebral levels, and so surgical judgment is still an important component in deciding which instrumented patients would benefit from immediate soft-tissue reconstruction.

A limitation of this meta-analysis is that the articles available for systematic review on the topic of spinal reconstruction were OCEBM level of evidence III and IV; therefore, the risk of selection bias confounding these data is considerable. We chose to only include studies published in the past 15 years, in an effort to limit technical and instrument-related heterogeneity. However, as indicated by the $I^2$ values, there was still interstudy heterogeneity when some variables were compared. This can be attributed to the fact that, owing to the small number of studies available, we chose to include all articles detailing immediate or delayed spinal wound reconstruction, regardless of the specific technique used, disease process, or patient population. We acknowledge that this decision introduces the potential for bias, but our intent was to maximize power for our statistical analyses. We believe that including only studies with high-level evidence on this focused topic would have generated underpowered, inconclusive, and irrelevant data analyses. Despite these limitations, the data do provide important information that support the concept of immediate wound reconstruction in high-risk patients.

## CONCLUSIONS

This systematic review has identified a number of wound healing risk factors that should prompt consideration for an immediate spinal wound reconstruction, such as previous spine surgery, the presence of spinal instrumentation, previous radiation therapy, a large resection defect, diabetes, obesity, and tobacco use. Paraspinous muscle flaps are most commonly used for both immediate and delayed reconstruction, can be employed at any vertebral level, and should be considered the first-line option. Our pooled analysis suggests that immediate soft-tissue reconstruction of high-risk spinal wounds is associated with fewer wound healing complications, fewer surgical-site infections, and increased hardware retention. However, additional studies are needed, in which simple primary closure is compared with immediate prophylactic paraspinous muscle flap reconstruction. Such a study would allow us to definitively risk stratify this patient population and accurately predict who would derive the greatest clinical benefit from an immediate soft-tissue reconstruction at the time of an index spine surgery.

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