Venous Thromboembolism in Spinal Fusion Surgery: A Literature Review of Economic Impact, Risk Factors, and Preoperative Management

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Abstract:

Study Design: Literature Review

Objectives: To conduct a comprehensive literature review about the risk factors and preoperative considerations that are related to postoperative venous thromboembolisms (VTEs) in patients who undergo spinal fusion.

Results: Postoperative VTEs are associated with higher costs and longer hospital stays for patients, in comparison to those who did not develop VTEs. Spinal level and multilevel fusion are risk factors for postoperative VTE. The effect of the surgical approach on VTE risk is unclear. Elevated BMI and age, kidney dysfunction, previous VTE, and primary hypercoagulability are preoperative risk factors for developing VTE. Intraoperative and postoperative risk factors for VTE include prolonged procedure time, discharge to inpatient facilities, and length of hospital stay. The effects of hypertension (HTN), sex, and dural tears on VTE risk in spinal fusion patients are uncertain. Chemoprophylaxis reduced the incidence of VTE. Tranexamic acid was not associated with an increase in VTE postoperatively. The American College of Surgeons National Surgical Quality Improvement Program surgical risk calculator served as a poor predictor of VTE incidence in spinal fusion. Preoperative D-dimer levels may help as a predictive tool.

Conclusions: To elucidate the effects of surgical approach, revision surgery, HTN, and dural tears on postoperative VTE risk, further research is warranted. To help identify high-risk patients, a risk calculator sensitive to VTE must be developed.

Keywords:

thromboembolism, risk factors, outcomes, spinal fusion, economic impact, prevention

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Introduction

Venous thrombosis refers to thrombus formation in the venous system. Deep vein thrombosis (DVT) is a venous thrombus formation in a deep vein. Embolism denotes the dislodging of a thrombus and its travel within the venous system. Pulmonary embolism (PE) is the travel of the thrombi to the lungs, which leads to the obstruction of venous structures. Collectively, PE and DVT are known as venous thromboembolism (VTE)[1]. VTE is a well-documented complication of orthopedic surgery, especially spinal fusion, and is associated with an increase in morbidity and mortality[2,3].

Spinal fusion is conducted to connect two or more vertebrae in the spine[4]. Indications for spinal fusion involve pain elicited by degenerative changes, neurologic dysfunctions secondary to spinal compression, symptomatic spondylolisthesis, scoliosis, and stabilization of unstable segments after trauma[4]. The rates of spinal fusion have increased by 118% between 1998 and 2014 with an annual increase in the number of procedures[5,6]. VTE incidence in patients undergoing spinal fusion ranges between 0.5% and 0.6%[2,7,8] but varies depending on multiple factors. Although infrequent, VTE remains a significant contributor to the cost of healthcare and with the increasing rates of spinal fusion procedures in the United States, the total number of postoperative VTEs is expected to increase[2,5,6,9].

The rates of nonfusion spinal procedures have been decreasing[5,6]. Given its increasing popularity, spinal fusion should be the focus of new research. Literature that investigates the preoperative risk factors for VTE in spinal surgery exists[2]. Nevertheless, articles that focus on spinal fusion do

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Table 1. Effects of Operative Characteristics on RISK of VTE.

Operative characteristics	OR	Summary
Cervical	–	Li et al. identified 204,308 patients who underwent spinal fusion. On multivariate analysis, cervical fusion was not associated with an increased likelihood of postoperative VTE[7].
Thoracic	1.87	Thoracic fusions were associated with a 1.87-fold increase likelihood of postoperative VTE compared with cervical fusions[7].
Lumbar	1.78	Lumbar fusion was the most common fusion level[7]. Lumbar fusions were associated with a 1.78-fold increase likelihood of postoperative VTE compared to cervical fusions[7].
Surgical approach	–	There is conflicting data regarding anterior versus posterior approaches. Cloney et al. found that anterior spinal fusions had a significant increase in postoperative VTE[14]. Although Li et al. found that posterior fusion was shown to have increased risk[7]. Further studies found that the risk was also dependent on the level[14].
Multilevel	1.93	Goz et al. defined multilevel fusion to include those with four or more segments. Multilevel fusion was associated with increased VTE risk[2,8].

not. In this review, we provide a summary of current literature about the risk factors and perioperative considerations for the development of postoperative VTE in patients undergoing spinal fusion. This review focuses on the risks of developing VTE at different spinal levels and approaches, perioperative risk factors for VTE, and chemoprophylaxis and risk prediction in VTE prevention.

Economic Impact

The incidence of VTEs ranges between 1.03%-10.7% in all spinal surgeries and 0.5%-0.6% in spinal fusion procedures[10]. VTEs disproportionately contribute to hospital costs associated with orthopedic surgery and spinal fusion in particular[2,9]. Therefore, VTEs incur a significant economic impact on the healthcare system. The mean hospital charges in spinal fusion patients who did and did not develop VTE were $207,253 and $66,823, respectively[2]. The mean duration of stay in the same cohort was 18.0 days in the VTE-positive group and 3.94 days in the VTE-negative group.

In a study looking at costs associated with 1,526,386 patients undergoing elective lumbar fusion for degenerative indications between 2002 and 2014, VTEs were found to be among the costliest adverse events[9]. Likewise, Ye et al. reported that VTE-positive patients undergoing posterior cervical fusion were 2.97 times more likely not to be discharged home (OR=2.97, 95% CI, 1.43-6.19, P=0.004), thus increasing the cost to the individual and healthcare system[11].

In a sample of 204,308 patients undergoing spinal fusion between 2006 and 2010, Li et al. reported that patients who developed a VTE were associated with a 4.5-day increase in length of stay when compared with those who did not (+136%, P<0.001)[7]. This was correlated with a $26,306 increase in overall payments (+62.7%, P<0.001). Those who developed at VTE were most likely to be readmitted, and later readmissions were associated with an increase in total payments ($19,290.58 at 6 months, 21,270.11 at 18 months, P=0.022). Therefore, Li et al. argued that the cost associated with VTE extends beyond the discharge of the patient postoperatively.

Operative Characteristics

Spinal fusion surgeries can be subdivided based on several operative characteristics. To analyze the incidence of VTEs in various spinal levels, surgical approaches, and degree of fusion, an investigation was carried out. Table 1 summarizes our findings.

1. Cervical

Incidence of VTE following cervical fusion surgery ranged from 0.28%-3.4%[7,12]. This figure can be further subdivided showing postoperative incidence rates of VTEs in anterior cervical fusion and posterior cervical fusion of 0.22% and 1.32%, respectively[2]. Li et al. identified 204,308 patients who underwent spinal fusion using the MarketScan database. To identify potential risk factors for postoperative PE and found that cervical fusion was not associated with an increased likelihood of postoperative VTE, the study utilized multivariate analysis[7].

2. Thoracic

Thoracic fusion was the least common fusion level[7]. The incidence of VTEs in this spinal region ranged from 0.59%-10.8%[7,12]. Anterior thoracic fusions had an incidence of 2.35%, whereas posterior thoracic fusions had an incidence of 2.46%[2]. Li et al. noted that thoracic fusions were associated with an increased likelihood of postoperative VTE (OR =1.87, 95% CI, 1.51-2.3, P<0.001)[7].

3. Lumbar

Lumbar fusion was the most common fusion level[7]. The incidence of VTE postoperatively at this level was 0.77% with VTE presentation occurring a median of 15 days after undergoing posterior lumbar interbody fusion (PLIF)[7,13]. Anterior lumbar fusion had a postoperative VTE incidence rate of 0.65%, with an incidence of 5.39% following anterior lumbar interbody fusion (ALIF)[2,8]. Likewise, posterior lumbar fusion (PLF) had an incidence rate of 0.45%-10.1%, and PLIF had an incidence rate of (9.1%)[2,12]. Moreover, Li et al. identified lumbar fusions as a factor that contributes to an

Table 2. Effects of Preoperative Risk Factors on RISK of VTE.

Preoperative risk factors	OR	Summary
Age	1.02–4.48	Multiple studies report a 1.02–4.48-fold increased risk of postoperative VTE in older patients[2,7,12,17,18]. McClendon et al. suggest that age may no longer be a significant risk factor in patients who are already at an increased risk of VTE[19].
Female sex	0.78	Goz et al. report that female sex is associated with a decreased risk of VTE (OR=0.78, P=0.0465)[2]. Other studies report conflicting evidence[12,19].
African American race	1.60	In comparison to white patients, African American patients are at a 1.60-fold increased risk of developing VTE after spinal fusion surgery[2]. No such trends were found in Hispanics or other races.
Obesity	1.44–6.15	Obesity is an independent risk factor for the development of VTE in patients undergoing spinal fusion[2,17,20]. McLynn et al. argue that the impact of obesity may be overestimated due to biases in ICD-10 coding[21].
Hypertension	0.82–1.24	Literature reported on the effect of Hypertension on the risk of VTE has been conflicting. Goz et al. report that, in 710,154 patients undergoing spinal fusion, hypertension was associated with a decreased risk of VTE[2]. Nevertheless, other studies have failed to demonstrate this relationship[7,18].
Diabetes	–	There has been limited evidence to suggest that DM is an independent predictor for the development of VTEs [2,15,18,22].
Kidney dysfunction	1.60	Renal failure is an independent risk factor for the development of VTE in patients undergoing spinal fusion[2]. However, this was not the case in patients undergoing multilevel fusion[15].
VTE history	8.03	McClendon et al. report that previous VTE History is an independent risk factor for postoperative VTE[19]. Additionally, patients with VTE history developed multiple VTEs and VTEs earlier on.
Hypercoagulability	1.72–12.19	Multiple studies report that primary and secondary hypercoagulability are independently associated with an increased risk of postoperative VTE [2,23,24].

increased likelihood of postoperative VTE (OR=1.78, 95% CI, 1.47-2.15, P<0.0001)[7].

4. *Surgical approach*

There is conflicting evidence on the differences in VTE risk in patients undergoing anterior and posterior spinal fusion. Cloney et al. investigated the approach of surgery as an independent variable in a multivariable regression model of 1,058 matched patients undergoing anterior and posterior lumbar fusions[14]. The incidence rate of VTE was 8.6% in patients undergoing anterior spinal fusion and 1.3% in patients undergoing posterior spinal fusion, a 7.2% difference (95% CI 2.28%-12.16%, P=0.004). By contrast, Li et al. reported an increased risk of VTE in patients undergoing posterior spinal fusion when compared with those undergoing anterior spinal fusion (OR=1.66, 95% CI, 1.43-2.15, P< 0.0001)[7]. Notably, Li's paper does not consider differences in VTE rates at different spinal regions. Nevertheless, revisiting the previous section, Goz et al. mentioned that anterior cervical fusion (OR=0.39, 95% CI, 0.22-0.68, P=0.0010) and PLF (OR=0.53, 95% CI, 0.33-0.85, P=0.0082) were significant factors in that were less likely associated with VTEs[2]. Interestingly, a combined anterior-posterior approach was noted to have a VTE incidence of 1.02% and was also significant in association with VTE incidence (OR=3.90, 95% CI, 1.83, 8.30, P=0.0004)[2].

5. *Multilevel fusion*

Literature related to multilevel fusion noted an increased level of VTE risk, but each defined "multilevel" differently. Yamasaki et al. defined it as involving six or more segments. When compared with other groups in their study, the long fusion group had a VTE incidence of 54.3%, which was significantly higher than other types of spinal procedures that they measured (P≤0.05)[15]. Goz et al. investigated fusion in four or more segments and discovered an incidence of 1.02%, which was associated with increased VTE incidence (OR=1.93, 95% CI, 1.31, 2.84, P=0.0009)[2].

Preoperative Risk Factors

Many comorbidities have been described in the literature pertaining to spinal fusion, with the most common being obesity, hypertension, and diabetes. The rates of comorbidities within patients undergoing spinal fusion have been increasing[16]. In 2006, 40% of patients undergoing anterior cervical discectomy and fusion (ACDF) had no comorbidities compared with 25.5% of patients in 2016 (P<0.001)[16]. Similar trends were observed in patients undergoing PLF (27.1% in 2006 and 19.9% in 2016, P<0.001)[16]. In this section, we review the patient characteristics and comorbidities (e.g., hypertension (HTN), DM, and CKD) associated with spinal fusion and their predisposition for VTE. Table 2 summarizes our findings.

1. Age

From 2006 to 2016, the median age of patients undergoing spinal fusion, such as ACDF and PLF, has increased[16].

Goz et al. reported age to be an independent risk factor for VTE in patients undergoing spinal fusion (OR=1.02, 95% CI, 1.02-1.03, P<0.0001)[2]. Likewise, Yoshioka et al. identified age as an independent risk factor for the development of VTE in patients undergoing spine surgery (OR= 1.042, 95% CI, 1.009-1.076, P=0.013)[12]. Multivariant analysis carried out by Phan et al. revealed that age >65 years was a statistically significant predictor of VTE (OR=4.48, 95% CI, 1.10-18.3, P=0.037) in patients undergoing posterior cervical fusion[17]. Li et al. also reported age >65 years to be an independent risk factor for the development of VTE (OR=1.39, 95% CI, 1.21-1.59, P<0.0001)[7]. Wei et al. found statistically significant differences in age between DVT-positive (Avg. age=61.3±10.3) and DVT-negative (Avg. age= 52.6±11.7) patients with PLIF (P=0.002)[18].

McClendon et al. reported no statistically significant correlation between age and VTE on logistic regression analysis (OR=0.987, 95% CI, 0.947-1.029, P=0.547) in "high-risk" patients undergoing multilevel spinal fusion with an IVC filter[19]. McClendon et al.'s results suggested that age may not be a risk factor in patients who are already at an increased risk of VTE (i.e., multilevel fusion, hypercoagulability, malignancy, smoking, and estrogen use). This is supported by the Yamasaki et al. results that indicated that among those undergoing multilevel lumbar spinal fusion, there is no significant difference in age (P=0.29) between DVT-positive (Avg. age=70.7±7.2) and DVT-negative (Avg. age=72.4±6.3) groups[15].

2. Sex

From 2006 to 2016, most patients undergoing ACDF and PLF have been female[16].

Goz et al. reported sex to be an independent risk factor for VTE in spinal fusion[2]. Multivariant analysis indicated that female sex is associated with a decreased risk of VTE (OR=0.78, 95% CI, 0.62-1.00, P=0.0465). Interestingly, Yoshioka et al. reported that in 459 patients undergoing spinal surgery (not limited to spinal fusion), the multivariant analysis indicated that the female sex was associated with an increased risk of VTE (OR=2.848, 95% CI, 1.342-6.044, P= 0.006)[12]. McClendon et al. found that in a population of 218 "high-risk" patients undergoing multilevel spinal fusion with an IVC filter, logistic regression identified sex as a significant risk factor for the development of acute VTE (OR= 0.243, 95% CI, 0.063-0.939, P=0.04) but did not indicate which sex was associated with an increased risk of VTE[19]. This was not true in populations of patients with multiple VTE events.

3. Race

Goz et al. reported VTE incidence in African American (AA) and white patients at 0.78% and 0.47%, respectively[2]. In comparison to white patients, AAs are at a higher risk of developing VTE after spinal fusion surgery (OR=1.60, 95% CI, 1.39-1.84, P<0.0001)[2]. They reported no statistically significant increase in VTE in Hispanics (OR=1.18, 95% CI, 0.96-1.45, P=0.1172) or other races (OR=1.06, 95% CI, 0.82-1.36, P=0.6717) when compared with white patients.

4. BMI

Goz et al. reported that obesity is an independent risk factor for the development of VTE in patients undergoing spinal fusion (OR=1.44, 95% CI, 1.26-1.66, P<0.0001)[2]. Alsoof et al. found that among 62,616 patients who were undergoing lumbar spinal fusion, obese (BMI=30-40) and morbidly obese (BMI>40) showed statistically significant increased odds of thromboembolism when compared to matched controls (Obese: OR=1.78, P<0.001; Morbidly Obese: OR=2.48, P<0.001)[20]. Underweight patients (BMI less than 20) presented no statistically significant difference in odds of thromboembolism when compared with matched controls (OR=1.25, P=0.813). Phan et al. found similar trends in 524 patients undergoing posterior cervical fusion[17]. Rates of VTE were significantly higher in patients with obese than nonobese (3.5% vs. 0.6%, P=0.015), and obesity was an independent risk factor for VTE (OR=6.15; 95% CI, 1.26-30.20, P=0.02). However, this study highlights that despite the elevated risk of VTE in patients with obesity, postoperative morbidity and mortality were not statistically increased in this population.

Although Goz et al., Alsoof et al., and Phan et al. provided compelling evidence for obesity as an independent risk factor for postspinal fusion VTE, McLynn et al. argued that obesity's impact may be overestimated[21]. McLynn et al. highlighted how administrative databases, similar to the PearlDiver Mariner database (Alsoof et al.) and the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) (Phan et al.), and biases in ICD coding for obesity "skew studies to suggest greater associated adverse event than calculated BMI would indicate," attributing this to tendencies of healthcare workers to assign ICD code for obesity to patients with other comorbidities and postoperative complications.

5. Hypertension

Goz et al. investigated the risk factors associated with VTE in 710,154 patients undergoing spinal fusion procedures[2]. Multivariant analysis indicated that hypertension was associated with a slightly decreased VTE incidence (OR= 0.82, 95% CI, 0.75-0.89, P<0.0001)[2]. A similar study, carried out by Li et al., investigated risk factors that are associated with VTE in 204,308 patients undergoing spinal fusion procedures. On multivariant analysis, they reported that hypertension is associated with an increased risk of VTE (OR= 1.24, 95% CI, 1.01-1.31, P=0.00377)[7].

Wei et al. assessed the preoperative risk factors for the incidence of DVT in patients undergoing PLIF[18]. Of the 2,861 patients included in the study, 269 were found to have DVT;

50.9% of DVT-positive and 58.2% of DVT-negative patients had a preoperative history of hypertension (P=0.066). Moreover, the multivariable analysis failed to reveal statistical significance for hypertension as a risk factor for the development of DVT in patients undergoing PLIF (OR=1.5422, P =0.156). Given the lack of consensus among these studies, to elucidate the effects of hypertension on the postoperative risk of developing VTE in patients undergoing spinal fusion, further research is needed.

6. Diabetes

Although DM is among the most common comorbid conditions that are associated with spinal fusion surgery, there has been limited evidence that suggests that DM is associated with increased VTE risk[22]. Univariate analysis done by Wei et al. and Yamasaki et al. revealed no significant difference in VTE rates between patients with and without DM[15,18]. Moreover, multivariate analysis carried out by Goz et al. presented an insignificant increase in the risk of VTE when a patient has diabetes (OR=1.08, 95% CI, 0.98-1.20, P =0.1219)[2].

7. Kidney dysfunction

Goz et al. reported that renal failure is an independent risk factor for the development of VTE in patients undergoing spinal fusion (OR=1.60, 95% CI, 1.30-1.96, P<0.0001)[2]. Nevertheless, in patients undergoing multilevel lumbar spinal fusion, Yamasaki et al. reported no significant risk differences in rates of CKD between DVT-positive (6.7%) and DVT-negative (4.8%) patients (P=0.65)[15]. The lack of statistical significance may be due to the study's small sample size. However, these results suggest that the increase in risk of VTE associated with kidney dysfunction may not be as significant in patients undergoing multilevel fusions and who are already at a relatively elevated risk of VTE. To confirm this, further research into the risk of VTE in patients with kidney dysfunction undergoing multilevel spinal fusion is necessary.

8. VTE history

McClendon et al. reported that in "high-risk" patients undergoing multilevel spinal fusion with an IVC filter, prior history of VTE is an independent risk factor for the development of acute VTE after spinal fusion (OR=8.032, 95% CI, 2.269-28.43, P=0.001)[19]. Furthermore, they reported that a prior history of VTE is an independent risk factor for the development of multiple VTE (95% CI, 0.210-0.675, P< 0.01). The average time to VTE after spinal fusion is 55.8 days (*SD*=5.3) and 10.8 days (*SD*=3.2) in patients without and with a history of VTE (P=0.03). Thus, researchers concluded that VTE history increases the rate of VTE development after spinal fusion.

9. Hypercoagulability

In patients undergoing spinal fusion, Goz et al. report that primary (e.g., protein C and S deficiency) and secondary hypercoagulability (e.g., pregnancy, autoimmune conditions, and myeloproliferative disorders) are independently associated with a 12.19-fold (OR=12.19, 95% CI, 8.88-16.73, P< 0.0001) and 3.63-fold (OR=3.63, 95% CI, 1.94-6.77, P= 0.0001) increase in risk of postoperative VTE, respectively[2]. Likewise, Bui et al. found that primary coagulation disorders were an independent risk factor for the development of VTE by three months (OR=3.96, P<0.001) in patients undergoing ACDF[23]. However, this was not the case in patients undergoing posterior cervical fusion. Puvanesarajah investigated the effect of coagulopathies on perioperative complications and outcomes in patients who underwent one- or two-level PLF[24]. They reported that patients with a primary hypercoagulable state (e.g., Factor V Leiden deficiency, hereditary protein C and S deficiency, and prothrombin gene mutations) had an increased risk of VTE within three months of surgery (OR=8.97, 95% CI, 7.61-10.59, P<0.0001). Patients with Von Willebrand disease or hemophilia were not associated with an increased risk of VTE (OR=1.72, 95% CI, 0.97-3.06, P=0.061).

Intraoperative and Postoperative Risk Factors

Numerous studies have outlined intraoperative and postoperative considerations that may play a role in the development of VTE. Such risk factors include the length of the spinal fusion procedure, length of stay after spinal fusion, location of discharge, and dural tear during spinal fusion. In this section, these intraoperative and postoperative considerations and the research on their predisposition for VTE are reviewed. Table 3 summarizes our findings.

1. Procedure time

Yoshioka et al. reported that in 459 patients undergoing spinal surgery (not limited to spinal fusion), there were no statistically significant differences (P=0.32) in operating time between those who were DVT positive (239.2±123.6 min) and DVT negative (226.9±117.6 min)[12]. In contrast, Tran et al. conducted a multivariant analysis in patients undergoing thoracolumbar spinal fusion, and results indicate that operation time is an independent predictor of VTE (OR=1.003, 95% CI 1.001-1.01, P=0.021)[25]. Additionally, they argued that for every hour of operative time, the risk of VTE increases by 18%. The average operative times for patients who developed and did not develop a DVT were 339±110 min and 262±175 min, respectively (P=0.010). Likewise, Ondeck et al. found that in 15,241 patients undergoing anterior cervical diskectomy and fusion, 15-min increases in surgical duration were associated with a 19% increase in rates of VTE[26]. Ondeck attributed the increase in VTE risk to anesthetic effects, physiologic stress, and surgical site issues.

2. Discharge location and length of stay

Khormaee et al. carried out a multivariable propensity-adjusted analysis on 18,652 patients undergoing PLF[27]. They reported that 0.43% and 1.08% of patients discharged to

Table 3. Effects of Intraoperative and Postoperative-preoperative Risk Factors on RISK of VTE.

Intraoperative and postoperative risk factors	OR	Summary
Prolonged procedure time	1.003	In patients undergoing thoracolumbar spinal fusion, operation time is an independent predictor of VTE[25]. Increases in surgery time by as little as 15 min were associated with a 19% increased risk of VTE[26].
Discharge location and length of stay	1.79	Khormaee et al. reported that discharge to inpatient facilities was an independent risk factor for the development of VTE[27]. This was attributed to immobility associated with bed rest and exposure to sick patients.
Dural tear	–	Love et al. concluded that DT is not associated with an increased risk of VTE after lumbar decompression and fusion[28]. Nevertheless, they highlight that their study is likely underpowered.

home and inpatient facilities developed VTE, respectively (P <0.001). Additionally, those discharged to inpatient facilities were more likely to be female, older, functionally dependent, have a higher BMI, and had a multilevel fusion than those discharged to home (P<0.001). Multivariable analysis indicated that discharge to inpatient facilities was an independent risk factor for the development of VTE (OR=1.79, 95% CI, 1.13-2.85, P=0.014). This was attributed to immobility associated with bed rest in care facilities and increased exposure to sick patients—both of which may increase the risk of VTE. Nevertheless, Yamasaki et al. reported that time to ambulation is not a significant risk factor for the development of VTE in patients undergoing spinal fusion of six or more segments (OR=1.21, 95% CI, 0.92-1.56, P=0.12). On logistic regression analysis, McClendon et al. found that length of hospital stay (OR=1.091, 95% CI, 1.045-1.138, P< 0.01) was an independent risk factor for the development of VTE in "high-risk" patients undergoing multilevel spinal fusion with an IVC filter[19].

3. *Dural tear*

Love et al. examined the effect of intraoperative dural tears on VTE prevalence in 611 patients undergoing lumbar decompression and fusion at a single institution[28]. They reported that 3.4% and 2.8% of patients without and with a dural tear developed a VTE after surgery (P=1.0). Hence, it was concluded that dural tear is not associated with an increased risk of VTE after lumbar decompression and fusion. Nonetheless, Love et al. highlighted that this study was likely underpowered to demonstrate statistical significance. Thus, to elucidate the increased risk of VTE in patients who developed dural tears while undergoing spinal fusion, further research may be warranted.

Preoperative and Postoperative Management

Current literature regarding measuring VTE risk using preoperative screening exists. In some studies, D-dimer has been found to be a possible quantifiable metric to assess VTE risk. Studies have also been carried out to support the role of chemoprophylaxis in deterring VTEs and analyze the safety of TXA use in these procedures.

1. *Chemoprophylaxis*

Chemoprophylaxis administration was determined to be a possible method of reducing postfusion VTE. Chemoprophylaxis utilized in studies were low-molecular-weight heparin, enoxaparin, dalteparin, and fondaparinux[19,29-31]. Cloney et al. noted a significant reduction in postoperative VTE in patients given chemoprophylaxis following lumbar spinal fusion surgery[31]. Interestingly, they reported no differences in rates of postoperative VTE in patients given chemoprophylaxis after spinal decompression surgery[31]. Moreover, timing may play a role in treatment. In one study, chemoprophylaxis administered less than 24 h postoperatively had a significant reduction in DVT development within 30 days of one or two-stage lumbar fusion (OR=0.189, 95% CI 0.044, 0.808, P=0.025)[29] but found no difference in DVT incidence between the groups that received chemoprophylaxis more than 24 h after surgery with the group that received no chemoprophylactic treatment[29]. By contrast, Dornbush et al. reported that early (<2 days postoperatively) and late (≥3 days postoperatively) administration of chemoprophylaxis did not influence VTE[30]. Another study also found that chemoprophylaxis was associated with reduced incidence on VTE in multilevel fusion (OR=0.82, 95% CI, 0.704-0.960, P= 0.013)[19]. Early anticoagulation may raise concern for bleeding complications. Nevertheless, two studies suggest that there is no significant difference in bleeding complications between early administration of chemoprophylaxis and both no anticoagulation and late administration in various fusion procedures[29,30].

2. *Tranexamic acid*

Tranexamic acid (TXA) is a synthetic antifibrinolytic drug utilized to reduce blood loss in surgery[32]. Studies have found that TXA may increase VTE incidence in some surgeries but did not specify spinal fusions[33]. Literature on TXA in spinal fusion and its association with VTEs focuses on lumbar fusions. Larson et al. administered TXA preoperatively and Ko et al. administered TXA 48 h postoperatively[32,33]. In both studies, patients administered TXA were compared with a control group that did not receive TXA. There were no significant differences in rates of VTE between the groups. Zhu et al., who focused on PLIFs, reported that two doses of TXA, the first dose 30 min before and the second dose 3 h after, significantly reduced total blood loss without increasing the risk of VTEs postoperatively[34]. This same pattern was reported by Kushioka et al. who explored the effects of a higher dose of TXA (20,000 mg) 15 min before and 16 h after PLIF on postoperative outcomes[35]. Topical TXA was examined in a single-level PLIF group, which showed reduced total blood loss and no increase in the risk of VTEs[36]. To address the concerns of increased VTE associated with TXA seen in other types of surgery, Li et al. employed TXA in combination with postoperative rivaroxaban, which presented significantly less intraoperative blood loss and decreased incidence of VTE[37]. Further research about TXA use in other spinal fusion procedures will need to be conducted.

3. Screening

The ACS NSQIP surgical risk calculator was developed to predict 30-day postoperative complications, including VTEs. When implemented to assess risk in ALIFs, it was a poor predictive tool for VTEs (AUC<0.70)[38]. When utilized to calculate the risk of complications in single-level PLFs, the risk calculator was suboptimal in all outcomes, except VTEs (c-statistic 0.66)[39].

4. D-dimer

D-dimer may help screen for increased VTE risk. In a group that underwent long fusion, a D-dimer of 19.5 μg/mL at one week postoperative was a risk factor for DVT (OR= 4.09, 95% CI, 2.82-7.88, P=0.02)[15]. Likewise, preoperative plasma D-dimer levels greater than 0.50 μg/mL were significantly associated with a higher incidence of DVT (P< 0.001)[18].

Conclusion

The number of VTEs is expected to increase with the increased frequency of spinal fusion surgery. In reducing the risk of this costly complication, understanding the preoperative and perioperative risk factors is essential. Physicians should be aware of the additional risk associated with spinal fusion involving certain levels and approaches as these factors will affect the patient's postoperative course. Further research should focus on elucidating the risks of HTN and dural tears as they pertain to the development of VTE in patients undergoing spinal fusion. Examining the role of CKD in patients undergoing multilevel spinal fusion may elucidate the interaction between CKD and the number of spinal levels fused. With the success shown with the utilization of chemoprophylaxis in the studies that were discussed, steps should be taken to implement similar protocols in hopes of reducing VTE risk. Furthermore, the development of a surgical risk calculator sensitive to VTE would screen for high-risk patients, allowing physicians to make educated decisions that will in turn impact patient outcomes.

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References

1. Hunt BJ. The prevention of hospital-acquired venous thromboembolism in the United Kingdom. Br J Haematol. 2009;144(5):642-52.
2. Goz V, McCarthy I, Weinreb JH, et al. Venous thromboembolic events after spinal fusion: which patients are at high risk? J Bone Joint Surg Am. 2014;96(11):936-42.
3. Zhang L, Cao H, Chen Y, et al. Risk factors for venous thromboembolism following spinal surgery: a meta-analysis. Medicine (Baltimore). 2020;99(29):e20954.
4. Mobbs RJ, Phan K, Malham G, et al. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg. 2015;1(1):2-18.
5. Sheikh SR, Thompson NR, Benzel E, et al. Can we justify it? Trends in the utilization of spinal fusions and associated reimbursement. Neurosurgery. 2020;86(2):E193-E202.
6. Reisener MJ, Pumberger M, Shue J, et al. Trends in lumbar spinal fusion-a literature review. J Spine Surg. 2020;6(4):752-61.
7. Li AY, Azad TD, Veeravagu A, et al. Impact of inpatient venous thromboembolism continues after discharge: retrospective propensity scored analysis in a longitudinal database. Clin Spine Surg. 2017;30(10):E1392-E8.
8. Nourian AA, Cunningham CM, Bagheri A, et al. Effect of anatomic variability and level of approach on perioperative vascular complications with anterior lumbar interbody fusion. Spine (Phila Pa 1976). 2016;41(2):E73-7.
9. Deng H, Yue JK, Ordaz A, et al. Elective lumbar fusion in the United States: national trends in inpatient complications and cost from 2002-2014. J Neurosurg Sci. 2021;65(5):503-12.
10. Schairer WW, Pedtke AC, Hu SS. Venous thromboembolism after spine surgery. Spine (Phila Pa 1976). 2014;39(11):911-8.
11. Ye I, Phan K, Cheung ZB, et al. Predictive risk factors of non-home discharge following elective posterior cervical fusion. World Neurosurg. 2018;119:e574-9.
12. Yoshioka K, Murakami H, Demura S, et al. Prevalence and risk factors for development of venous thromboembolism after degenerative spinal surgery. Spine (Phila Pa 1976). 2015;40(5):E301-6.
13. Kammien AJ, Zhu JR, Gillinov SM, et al. Adverse events after posterior lumbar fusion are not sufficiently characterized with 30-day follow-up: a database study. J Am Acad Orthop Surg. 2022;30(11):528-33.

14. Cloney MB, Hopkins B, Dhillon E, et al. Anterior approach lumbar fusions cause a marked increase in thromboembolic events: causal inferences from a propensity-matched analysis of 1147 patients. Clin Neurol Neurosurg. 2022;223:107506.

15. Yamasaki K, Hoshino M, Omori K, et al. Prevalence and risk factors of deep vein thrombosis in patients undergoing lumbar spine surgery. J Orthop Sci. 2017;22(6):1021-5.

16. Wilson LA, Fiasconaro M, Liu J, et al. Trends in comorbidities and complications among patients undergoing inpatient spine surgery. Spine (Phila Pa 1976). 2020;45(18):1299-308.

17. Phan K, Kothari P, Lee NJ, et al. Impact of obesity on outcomes in adults undergoing elective posterior cervical fusion. Spine (Phila Pa 1976). 2017;42(4):261-6.

18. Wei J, Li W, Pei Y, et al. Clinical analysis of preoperative risk factors for the incidence of deep venous thromboembolism in patients undergoing posterior lumbar interbody fusion. J Orthop Surg Res. 2016;11(1):68.

19. McClendon J, Jr., Smith TR, O'Shaughnessy BA, et al. Time to event analysis for the development of venous thromboembolism after spinal fusion >/= 5 levels. World Neurosurg. 2015;84(3):826-33.

20. Alsoof D, Johnson K, McDonald CL, et al. Body mass index and risk of complications after posterior lumbar spine fusion: a matched cohort analysis investigating underweight and obese patients. J Am Acad Orthop Surg. 2023;31(7):e394-402.

21. McLynn RP, Geddes BJ, Cui JJ, et al. Inaccuracies in ICD coding for obesity would be expected to bias administrative database spine studies toward overestimating the impact of obesity on perioperative adverse outcomes. Spine (Phila Pa 1976). 2018;43(7):526-32.

22. Hopkins BS, Patel MR, Yamaguchi JT, et al. Predictors of patient satisfaction and survey participation after spine surgery: a retrospective review of 17,853 consecutive spinal patients from a single academic institution. Part 1: Press Ganey. J Neurosurg Spine. 2019;30(3):389-8.

23. Bui A, Lashkari N, Formanek B, et al. Incidence and risk factors for postoperative venous thromboembolic events in patients undergoing cervical spine surgery. Clin Spine Surg. 2021;34(8):E458-65.

24. Puvanesarajah V, Jain A, Shimer AL, et al. The effect of coagulopathies on perioperative complications and clinical outcomes in patients treated with posterior lumbar fusions. Spine (Phila Pa 1976). 2016;41(17):E1063-8.

25. Tran KS, Issa TZ, Lee Y, et al. Impact of prolonged operative duration on postoperative symptomatic venous thromboembolic events after thoracolumbar spine surgery. World Neurosurg. 2023;169:e214-20.

26. Ondeck NT, Bohl DD, McLynn RP, et al. Longer operative time is associated with increased adverse events after anterior cervical diskectomy and fusion: 15-minute intervals matter. Orthopedics. 2018;41(4):e483-8.

27. Khormaee S, Samuel AM, Schairer WW, et al. Discharge to inpatient facilities after lumbar fusion surgery is associated with increased postoperative venous thromboembolism and readmissions. Spine J. 2019;19(3):430-6.

28. Love D, Bruckner J, Ye I, et al. Dural tear does not increase the rate of venous thromboembolic disease in patients undergoing elective lumbar decompression with instrumented fusion. World Neurosurg. 2021;154:e649-55.

29. Kiguchi MM, Schobel H, TenEyck E, et al. The risks and benefits of early venous thromboembolism prophylaxis after elective spinal surgery: a single-centre experience. J Perioper Pract. 2022;32(11):286-94.

30. Dornbush C, Maly C, Bartschat N, et al. Chemoprophylaxis timing is not associated with postoperative bleeding after spinal trauma surgery. Clin Neurol Neurosurg. 2023;225:107590.

31. Cloney MB, Hopkins B, Dhillon E, et al. Chemoprophylactic anticoagulation following lumbar surgery significantly reduces thromboembolic events after instrumented fusions, not decompressions. Spine (Phila Pa 1976). 2023;48(3):172-9.

32. Larson E, Evans T, Long J, et al. Does prophylactic administration of TXA reduce mean operative time and postoperative blood loss in posterior approach lumbar spinal fusion surgery performed for degenerative spinal disease? Clin Spine Surg. 2019;32(7):E353-8.

33. Ko BS, Cho KJ, Kim YT, et al. Does tranexamic acid increase the incidence of thromboembolism after spinal fusion surgery? Clin Spine Surg. 2020;33(2):E71-5.

34. Zhu X, Shi Q, Li D, et al. Two doses of tranexamic acid reduce blood loss in primary posterior lumbar fusion surgery: a randomized-controlled trial. Clin Spine Surg. 2020;33(10):E593-7.

35. Kushioka J, Yamashita T, Okuda S, et al. High-dose tranexamic acid reduces intraoperative and postoperative blood loss in posterior lumbar interbody fusion. J Neurosurg Spine. 2017;26(3):363-7.

36. Shi P, Wang J, Cai T, et al. Safety and efficacy of topical administration of tranexamic acid in high-risk patients undergoing posterior lumbar interbody fusion surgery. World Neurosurg. 2021;151:e621-9.

37. Zhang L, Li Y, Liu D, et al. Combined use of tranexamic acid and rivaroxaban in posterior lumbar interbody fusion safely reduces blood loss and transfusion rates without increasing the risk of thrombosis-a prospective, stratified, randomized, controlled trial. Int Orthop. 2020;44(10):2079-87.

38. Narain AS, Kitto AZ, Braun B, et al. Does the ACS NSQIP surgical risk calculator accurately predict complications rates after anterior lumbar interbody fusion procedures? Spine (Phila Pa 1976). 2021;46(12):E655-62.

39. Sebastian A, Goyal A, Alvi MA, et al. Assessing the performance of national surgical quality improvement program surgical risk calculator in elective spine surgery: insights from patients undergoing single-level posterior lumbar fusion. World Neurosurg. 2019;126:e323-9.

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