Article

Factors Influencing the Indwelling Time of Retrievable Inferior Vena Cava Filters in Fracture Patients With Deep Vein Thrombosis: A Retrospective Cohort Study

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AIM: To investigate factors influencing the indwelling time of retrievable inferior vena cava filters (IVCFs) in fracture patients with deep vein thrombosis (DVT), particularly comparing Denali and Cordis filters and analyzing the impact of thrombus location and patient characteristics.
METHODS: A retrospective cohort study was conducted from June 2017 to December 2021 at Shenyang Orthopedic Hospital, China. We analyzed 802 patients with fractures and acute DVT who underwent successful IVCF retrieval. Patients were stratified into Denali (n = 360) and Cordis (n = 442) groups, with DVT categorized into four subgroups: above-knee DVT (AKDVT), popliteal vein thrombosis (PVT), below-knee DVT (BKDVT), and mixed DVT (MDVT). The normality of continuous variables was assessed using the Kolmogorov-Smirnov test ($p \geq 0.05$). Statistical analyses included Cox regression for hazard ratios (HRs), independent *t*-tests for normally distributed variables, chi-square tests for categorical variables (e.g., gender, diabetes prevalence), and Mann-Whitney U tests for non-normally distributed variables.
RESULTS: A total of 802 patients underwent IVCF insertion and had their filters successfully removed. Significant differences in the indwelling time for AKDVT, PVT, BKDVT, and MDVT were observed between the Denali and Cordis groups ($p < 0.001$). In the Denali group, the indwelling times for AKDVT, PVT, BKDVT, and MDVT were 58, 67, 42, and 51 days, respectively, while in the Cordis group, the corresponding times were 21, 15.5, 16, and 19 days ($p < 0.001$). Cox regression analysis revealed that age influenced the indwelling time in the Denali group. In both the Denali and Cordis groups, metabolic factors such as diabetes, hypertension, and blood lipids were not significantly correlated with indwelling time ($p > 0.05$). Multivariate Cox regression identified that age ≥60 years (adjusted HR = 1.3, 95% confidence interval (CI) = 1.051–1.609, $p = 0.016$) and BKDVT (BKDVT vs. AKDVT: HR = 1.802, 95% CI = 1.029–3.157, $p = 0.039$) were predictors of prolonged indwelling time in the Denali group, while PVT ($p = 0.943$) and MDVT ($p = 0.831$) showed no significant association.
CONCLUSIONS: Denali filters require longer indwelling durations than Cordis filters, with age and DVT location (BKDVT) being critical determinants for Denali, whereas only DVT location affects Cordis. Clinicians should tailor follow-up schedules and prioritize early retrieval for Cordis filters to reduce complications. These findings underscore the importance of individualized IVCF management based on filter type and thrombus location.

Keywords: indwelling time; IVCFs; DVT

Introduction

Pulmonary embolism (PE) is a life-threatening condition and remains a significant cause of morbidity and mortality worldwide [1,2]. Inferior vena cava filters (IVCFs) were introduced in 1973 [3], with the primary objective of capturing embolic thrombi originating from the lower extremity veins. This intervention aims to prevent clinically significant PE in patients who cannot safely undergo anticoagulation during the perioperative period [4,5]. However, permanent IVCFs have been associated with significant long-term complications, including inferior vena cava stenosis or occlusion (9.3% incidence; 95% confidence interval (CI), 7.1–11.8%) [6], symptomatic recurrent deep vein thrombosis (5-year cumulative incidence of 21.4%, hazard ratio (HR) = 1.83, $p = 0.004$ compared with retrievable filters) [7], stent penetration (≥3 mm in 32% of cases; organ damage in 7.5%) [8], and filter fracture (3.8% risk within 8 years) [8].

Retrievable IVCFs were introduced in 2003 to mitigate these complications, but the optimal indwelling time remains a topic of ongoing debate [9]. While previous studies

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have evaluated general trauma populations, no investigation has specifically compared the performance of different retrievable IVCFs, namely, Denali versus Cordis, in fracture patients with deep vein thrombosis (DVT), nor have they evaluated how thrombus location may interact with filter design to influence indwelling time. This knowledge gap limits the development of individualized management strategies for high-risk populations.

Following the recognition of these risks, retrievable filters were developed. The first retrievable IVCFs received approval from the USA Food and Drug Administration (FDA) in 2003 and were made available for PE prevention. However, their widespread use was soon accompanied by accounts of filter-related complications and unsatisfactory retrieval rates [10,11]. Current clinical indications of IVCF placement include recurrent venous thromboembolism (VTE) or progression of DVT despite adequate anticoagulant therapy. Other indications involve contraindications to anticoagulation, a history of catheter-directed thrombolysis, large free-floating proximal DVT in the vena cava or iliac veins, and cases requiring percutaneous mechanical thrombectomy or surgical embolectomy. Filters may also be placed prophylactically in trauma patients or prior bariatric pelvic, or lower limb surgical interventions, especially when ipsilateral DVT is present [12–15].

Orthopedic trauma patients represent an important subgroup for these indications. Lower extremity fractures are associated with a 12–34% risk of DVT due to deterioration of Virchow's triad caused by immobilization, endothelial damage during fracture reduction, and a surgery-induced hypercoagulable state [16]. Notably, 23% of patients with pelvic fractures developed proximal DVT within 72 hours of injury, and 8.2% required IVCF placement prior to internal fixation to mitigate the risk of intraoperative embolism [17]. These adverse outcomes prompted the issuance of an FDA Safety Advisory in 2010, which was updated in 2014. This advisory recommended that implanting physicians and healthcare providers involved in the continued care of patients with retrievable IVCFs should consider removing the filter as soon as protection against PE is no longer needed [10].

The use of retrievable IVCFs is recommended when the risk of PE has diminished, and the filter has served its intended protective role, typically within 90 days of implantation. Accordingly, it is advised that filters be extracted within this 90-day period following their insertion [18]. The FDA further suggests that IVCF placement be guided by clear and appropriate clinical indications and that their removal be planned within 29 to 54 days post-implantation [19]. Prolonged utilization of these filters may result in severe complications, including perforation of adjacent tissues or filter rupture.

In our study, we evaluated patients with fractures complicated by DVT who had received IVCF placement before fracture surgery. To date, no studies have directly compared Denali and Cordis filters in this population, nor have they explored how thrombus location interacts with filter type to influence indwelling time. Our study aimed to provide clinically relevant insights to inform and improve individualized care in such cases.

Methods

Study Design and Participants

This was a single-center, retrospective cohort study. The project was approved by the Ethics Committee of Shenyang Orthopedic Hospital, and written informed consent was obtained from all participants (approval no. 2022-KY-002-02). The study was conducted in accordance with the principles outlined in the Declaration of Helsinki. A total of 1005 patients who underwent implantation of Denali or Cordis retrievable IVCFs between June 2017 and December 2021 at Shenyang Orthopedic Hospital, China, were enrolled (technical success rate of IVCFs implantation was 100%). Of these, 199 patients (19.8%) were lost to follow-up (including one death, and 198 patients either withdrew due to economic reasons, received retrieval at another hospital, or declined filter retrieval). Additionally, four patients failed to remove the filter. Consequently, the final analysis included 802 patients with successful filter retrieval, including 360 patients with Denali filters and 442 with Cordis filters. Patient demographics and filter retrieval procedures were recorded. Based on DVT location, the patients were divided into four groups: above-knee DVT (AKDVT), below-knee DVT (BKDVT), popliteal vein thrombosis (PVT) group, and mixed DVT (MDVT).

Diagnosis of DVT

A certified vascular sonographer performed a bilateral lower extremity venous Doppler ultrasound to diagnose acute DVT. Ultrasound diagnostic ultrasound criteria for DVT included:

(1) Incomplete venous lumen compressibility (compression rate $<50\%$) under probe pressure (4 N/cm^2); (2) Presence of immobile hyperechoic material ≥ 5 mm in length within the venous lumen on two-dimensional gray-scale imaging; (3) Absence of spontaneous venous blood flow and no phasic blood flow enhancement (flow velocity change $<20\%$) during distal limb compression on Doppler imaging; (4) Reduced respiratory variability ($<10\%$) in the spectral Doppler waveform of the proximal vein.

All examinations followed the standardized procedures recommended by the Society of Radiologists in Ultrasound (SRU) consensus guidelines for venous thrombosis detection. Suspected or equivocal cases underwent follow-up ultrasonography or supplemental imaging (e.g., computed tomographic venography) within 24 hours for confirmation.

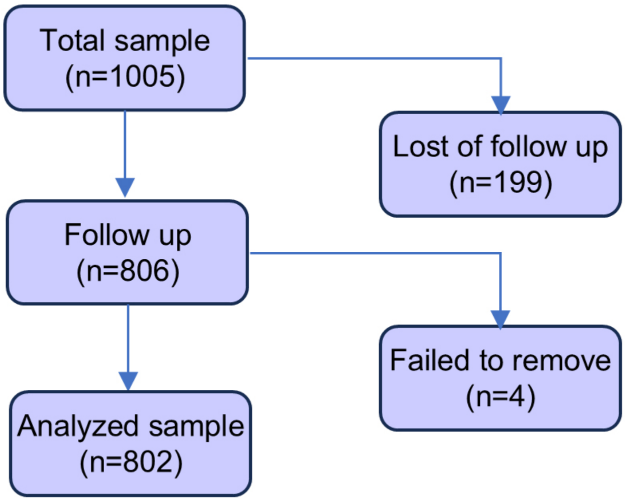

Fig. 1. Flow chart of patient selection. This flowchart illustrates the screening, enrollment, follow-up, and final analysis of patients with fractures and deep vein thrombosis (DVT) who underwent implantation of retrievable inferior vena cava filters (IVCFs). A total of 1005 patients met the inclusion criteria and successfully received IVCF placement (technical success rate: 100%). A total of 199 patients (19.8%) were lost to follow-up, including 1 death and 198 cases due to economic constraints, transfer to other institutions, or refusal of filter retrieval. Filter removal failed in 4 patients. The final analysis included 802 patients (438 males, 364 females) who completed follow-up and underwent successful filter retrieval. Fig. 1 was created using Microsoft PowerPoint (Microsoft 365, Microsoft Corp., Redmond, WA, USA).

Filter Placement and Retrieval Indication

Indications for Filter Placement

In alignment with the Guidelines for Diagnosis and Treatment of Deep Vein Thrombosis (3rd edition) [20] issued by the Chinese Society of Vascular Surgery, Chinese Association of Orthopedics, American College of Chest Physicians, Society of Interventional Radiology [21], and the British Committee for Standards in Hematology for Therapy of Venous Thromboembolic Disease, as well as the Shenyang Orthopedic Hospital's academic committee, comprising specialists in vascular and orthopedic surgery, established these indications for IVCFs placement in patients with acute bone trauma: the presence of acute DVT with the proximal thrombus located above the knee in patients with spinal, pelvic, femoral, or multiple fractures requiring surgery; and DVT in patients undergoing surgical repair of fractures involving the knee or distal regions in the ipsilateral limb.

Filter-retrieval Indications

The indications for filter retrieval were as follows: after comprehensive clinical examinations and evaluations, the DVT had resolved or remained in a stable state, and two D-dimer test results were normal within 15 days; the risk of clinically significant PE had decreased to an acceptable level due to sustained and appropriate primary treatment (therapeutic or prophylactic) or changes in clinical condition; there was no anticipated high-risk status of PE due to primary treatment interruption, alterations in therapy, or changes in clinical conditions; the patient was young or expected to derive benefit from filter retrieval; based on thorough evaluations, the filter could be safely retrieved or converted; the patient or legal guardian consented to filter retrieval or conversion; and the filter indwelling time did not exceed the recommended recovery window. In cases where patients strongly requested filter removal, the retrieval window was extended appropriately [22].

Data Visualization

The patient selection flowchart was shown in Fig. 1.

Statistics Analyses

Statistical analyses were performed using SPSS version 23.0 (IBM Corp., Armonk, NY, USA; available at: https://www.ibm.com/products/spss-statistics). Data are presented as means $\pm$ standard deviations for normally distributed continuous variables, medians (interquartile ranges) for non-normally distributed variables, and frequencies (percentages) for categorical variables. The Kolmogorov-Smirnov test was used to assess the normality of continuous variables ($p \geq 0.05$ indicated normal distribution). Non-normal distributed data (such as filter indwelling time) were analyzed using the Mann-Whitney U test for two-group comparisons and the Kruskal-Wallis H test for multi-group comparisons. Differences between groups were analyzed using independent sample *t*-tests for normally distributed continuous variables (e.g., glycated hemoglobin A1c (HbA1c)) and chi-square tests for categorical variables (e.g., gender, prevalence of diabetes). A two-tailed *p*-value < 0.05 was considered statistically significant for all analyses.

The IVCF indwelling time was treated as the time-to-event outcome, with successful filter retrieval defined as the event (event = 1). Cox proportional hazards regression models were used for univariate and multivariate analyses to identify factors influencing filter indwelling time. Univariate analysis was used to estimate crude hazard ratios (HRs) and 95% confidence intervals (CIs) of each potential factor. Variables with $p < 0.05$ in univariate analysis (such as age $\geq$60 years and BKDVT) were included in the multivariate analysis, with verification of the proportional hazards assumption. Subgroup analysis was conducted using the Kruskal-Wallis H test to compare the differences in filter indwelling time among different DVT locations, with Bonferroni correction applied to control type I error. Additionally, stratified sensitivity analyses by age group and DVT location were performed to verify the robustness of the results.

Results

Clinical Characteristics of Patients According to Different Retrievable IVCFs

Since different types of retrievable filters have distinct optimal removal times, patients were grouped based on the model of the filter. Among the 802 patients, 360 had Denali filters, and 442 had Cordis filters. No significant differences were observed between the groups in terms of age (Denali: 61.60 ± 14.35 vs. Cordis: 59.69 ± 15.26 years, p = 0.082), gender distribution (male: 53.06% vs. 55.88%, p = 0.413), the prevalence of diabetes (15.83% vs. 13.80%, p = 0.419), the prevalence of hypertension (51.39% vs. 50.23%, p = 0.729), or overall DVT subgroup distribution (AKDVT, PVT, BKDVT, MDVT; p = 0.474). Furthermore, there were no significant differences in systolic blood pressure, diastolic blood pressure, fasting blood glucose, triglyceride (TG), total cholesterol (TC), and low-density lipoprotein cholesterol (LDL-C) levels between the two groups (all $p > 0.05$). However, glycated hemoglobin A1c (HbA1c) was significantly higher in the Denali group than in the Cordis group (5.95% ± 1.12 vs. 5.74% ± 1.26, p = 0.010). Additionally, the high-density lipoprotein cholesterol (HDL-C) level was significantly lower in the Denali group compared to the Cordis group (1.19 ± 0.34 mmol/L vs. 1.33 ± 0.41 mmol/L, $p < 0.001$). The median indwelling time of IVCFs in the Cordis group (45.0 [interquartile range (IQR): 35.0–63.0] days) was significantly longer than that in the Denali group (17.0 [IQR: 15.0–20.0] days, $p < 0.001$). A summary of the clinical characteristics is presented in Table 1.

Comparison of Indwelling Times for Different Filter Models According to the Location of DVT

To evaluate the indwelling duration of retrievable IVCFs across various DVT locations, we conducted multi-group and pairwise comparisons. Significant differences in indwelling times were observed among the AKDVT, PVT, BKDVT, and MDVT subgroups in both the Denali and Cordis groups ($p < 0.001$). In the Denali group, median indwelling times for the AKDVT, PVT, BKDVT, and MDVT subgroups were 58, 67, 42, and 51 days, respectively ($p <$ 0.001). Pairwise comparisons revealed significant differences between the AKDVT and BKDVT groups, and between the BKDVT and MDVT groups ($p < 0.05$). In the Cordis group, median indwelling times for the AKDVT, PVT, BKDVT, and MDVT subgroups were 21, 15.5, 16, and 19 days, respectively ($p < 0.001$). Significant differences in indwelling time were noted between AKDVT and PVT, AKDVT and BKDVT, PVT and MDVT, and BKDVT and MDVT groups ($p < 0.05$, Table 2).

Univariate Cox Regression Analysis of the Factors Influencing the Indwelling Time of IVCFs

Univariate Cox regression analysis showed that the influence of various factors on IVCF indwelling time was significantly different between the Denali and Cordis groups. In the Denali group, patients aged ≥60 years had a 31.4% increased risk of prolonged indwelling time compared with those <60 years (crude HR = 1.314, 95% CI = 1.062–1.625, p = 0.012). In contrast, the effect of age in the Cordis group approached but did not reach statistical significance (HR = 1.202, 95% CI = 0.996–1.450, p = 0.055).

In terms of thrombus location, in the Denali group, the risk of prolonged indwelling time in patients with below-knee DVT (BKDVT) was 85.2% higher than those with above-knee DVT (AKDVT) (HR = 1.852, 95% CI = 1.058–3.242, p = 0.031). No significant differences were observed for popliteal vein thrombosis (PVT: HR = 1.028, p = 0.946) or mixed DVT (MDVT: HR = 1.087, p = 0.778). In the Cordis group, both PVT (HR = 3.421, 95% CI = 1.661–7.045, p = 0.001) and BKDVT (HR = 2.168, 95% CI = 1.374–3.421, p = 0.001) were significantly associated with longer indwelling time. However, MDVT was not significantly associated with filter retention time (HR = 1.460, p = 0.121).

Metabolic factors, including diabetes mellitus (Denali group: HR = 1.024, p = 0.871; Cordis group: HR = 1.092, p = 0.527), hypertension (Denali group: HR = 1.009, p = 0.931; Cordis group: HR = 0.937, p = 0.497), and blood lipid parameters (TG, TC, HDL-C, LDL-C) were not significantly associated with indwelling time in either group (all $p > 0.05$). Additionally, gender, systolic and diastolic blood pressure, HbA1c, and fasting blood glucose levels were not associated with filter indwelling time (Table 3).

Multivariate Cox Regression Analysis of the Factors Influencing IVCF Indwelling Time

Since only the Denali group exhibited two statistically significant risk factors in the univariate analysis, multivariate Cox regression analysis was performed solely for this group. Variables with statistical significance from the univariate analysis were entered into a stepwise multivariate Cox regression model. Our results showed that age and DVT location were significantly associated with indwelling time. Patients aged ≥60 years had an adjusted HR of 1.3 (95% CI = 1.051–1.609, $p < 0.05$). According to the location of the DVT, only the BKDVT group showed a statistically significant difference compared to the AKDVT group, with an adjusted HR of 1.802 (95% CI = 1.029–3.157, $p <$ 0.05) (Table 4).

Discussion

Venous thromboembolism (VTE) represents the predominant major complication among orthopedic trauma patients [23,24], while inferior vena cava filters (IVCFs) are engineered to intercept lower extremity emboli and mitigate significant pulmonary embolism (PE) events [5]. The placement of an IVCF serves as an efficient strategy to prevent potentially fatal perioperative PE in trauma patients and plays a vital role in the management of VTE in this pop-

Table 1. Baseline characteristics of patients receiving Denali or Cordis IVCFs.

Variable	Total	Denali	Cordis	χ^2/t/z	p-value
Age (years)	60.55 ± 14.88	61.60 ± 14.35	59.69 ± 15.26	1.74	0.082
<60 (n, %)	345 (43.02)	142 (39.44)	203 (45.93)		
≥60 (n, %)	457 (56.98)	218 (60.56)	239 (54.07)		
Gender (n, %)				0.67	0.413
Male	438 (54.61)	191 (53.06)	247 (55.88)		
Female	364 (45.39)	169 (46.94)	195 (44.12)		
DVT Type (n, %)				2.51	0.474
AKDVT	34 (4.24)	13 (3.61)	21 (4.75)		
PVT	23 (2.87)	11 (3.06)	12 (2.71)		
BKDVT	548 (68.33)	239 (66.39)	309 (69.91)		
MDVT	197 (24.56)	97 (26.94)	100 (22.62)		
Diabetes (n, %)	118 (14.71)	57 (15.83)	61 (13.80)	0.65	0.419
Hypertension (n, %)	407 (50.75)	185 (51.39)	222 (50.23)	0.12	0.729
SBP (mmHg)	139.34 ± 21.64	139.64 ± 20.55	139.08 ± 22.50	0.34	0.734
DBP (mmHg)	80.07 ± 12.62	79.72 ± 12.04	80.35 ± 13.07	0.67	0.505
HbA1c (%)	5.84 ± 1.21	5.95 ± 1.12	5.74 ± 1.26	2.59	0.010
FBG (mmol/L)	6.59 ± 2.15	6.61 ± 1.94	6.57 ± 2.31	0.28	0.782
TG (mmol/L)	1.46 (1.06, 1.97)	1.46 (1.06, 1.95)	1.45 (1.05, 1.99)	0.30	0.763
TC (mmol/L)	4.59 ± 1.04	4.56 ± 1.00	4.62 ± 1.07	0.79	0.430
HDL-C (mmol/L)	1.27 ± 0.38	1.19 ± 0.34	1.33 ± 0.41	5.02	<0.001
LDL-C (mmol/L)	2.37 ± 0.85	2.35 ± 0.77	2.38 ± 0.91	0.49	0.624
Indwelling time (days)	22.0 (16.0, 43.0)	17.0 (15.0, 20.0)	45.0 (35.0, 63.0)	23.53	<0.001

Abbreviations: AKDVT, above-knee deep venous thrombosis; PVT, popliteal vein thrombosis; BKDVT, below-knee deep venous thrombosis; MDVT, mixed deep venous thrombosis; SBP, systolic blood pressure; DBP, diastolic blood pressure; HbA1c, glycated hemoglobin A1c; FBG, fasting blood-glucose; TG, triglyceride; TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol. p-values are considered statistically significant at α = 0.05. Continuous variables were compared using independent t-tests or Mann-Whitney U tests based on normality assessment using Kolmogorov-Smirnov test.

ulation [25,26]. The clinical utility of retrievable IVCFs remains a subject of debate. The controversy primarily stems from the observation that a relatively long implantation time in the body may lead to more complications, such as filter displacement, thrombosis, and potential retrieval failure. The retrievability of IVCFs can vary significantly depending on their design and manufacturer specifications, allowing for potential retrieval windows ranging from several weeks to several months. For instance, studies have revealed a significantly elevated risk of retrieval-related complications when IVCFs are left in situ for more than six months in trauma populations [27]. Another study further established that the complication rates, both post-procedural and retrieval-related, were significantly associated with extended indwelling times, while such complications were rarely observed within the first 30 days [28]. Thus, retrievable IVCFs should be removed as soon as clinically feasible once the risk of PE has subsided, ideally within eight weeks post-implantation [29], although most manufacturers permit retrieval up to one year [30]. A large-scale analysis of 270,866 medical insurance claims showed that the risk of filter-related complications increased non-linearly over time: within 30 days the retrieval success rate was 93.5% with a 1.4% complication rate [31]; between 30–90 days, the incidence of DVT increased from 4.1% to 9.2% (HR = 1.83, $p < 0.001$) [32]; and after 90 days, 32% of filters showed stent penetration (7.5% symptomatic), with 3.8% fracture risk [31,33].

A meta-analysis involving 12,753 trauma patients showed that IVCFs predominantly captured acute thrombotic fragments generated by fracture reduction within the first 14 days, during which time the risk of PE was reduced by 87% (RR = 0.13, 95% CI = 0.08–0.21) [34]. After 28 days, the thrombus capture efficacy declined as endothelialization progressively covered more than 30% of the filter surface, thereby reducing its function [35]. Practically, it is essential to evaluate the balance between the overall risks and potential benefits and to ensure that planned filter removal occurs within a timeframe that minimizes potential complications [36].

Although we advocate for the timely removal of the filter within a clinically safe timeframe, a consensus on the optimal indwelling duration has yet to be established. Accordingly, this investigation aimed to contribute additional clin-

Table 2. Indwelling time by filter model according to DVT location.

DVT Type	Denali		Cordis	
	Placement time (day)	p-value	Placement time (day)	p-value
AKDVT	58.0 (45.5–73.0)	<0.001	21.0 (16.0–23.0)	<0.001
PVT	67.0 (35.0–86.0)		15.5 (13.3–17.5)^{a}	
BKDVT	42.0 (34.0–57.0)^{a}		16.0 (15.0–20.0)^{a}	
MDVT	51.0 (39.5–79.5)^{c}		19.0 (15.0–21.0)^{bc}	

Note: Compared with AKDVT, $^{a}p < 0.001$; Compared with PVT, $^{b}p < 0.001$; Compared with BKDVT, $^{c}p < 0.001$.

Table 3. Univariate Cox regression analysis of factors influencing IVCF indwelling time.

Variable	Denali		Cordis	
	Crude HR (95% CI)	p-value	Crude HR (95% CI)	p-value
Age (years)				
<60	Ref		Ref	
≥60	1.314 (1.062–1.625)	0.012	1.202 (0.996–1.450)	0.055
Gender				
Male	Ref		Ref	
Female	1.060 (0.861–1.305)	0.585	1.026 (0.850–1.239)	0.790
DVT Type				
AKDVT	Ref		Ref	
PVT	1.028 (0.460–2.301)	0.946	3.421 (1.661–7.045)	0.001
BKDVT	1.852 (1.058–3.242)	0.031	2.168 (1.374–3.421)	0.001
MDVT	1.087 (0.609–1.941)	0.778	1.460 (0.905–2.353)	0.121
Diabetes	1.024 (0.770–1.361)	0.871	1.092 (0.832–1.433)	0.527
Hypertension	1.009 (0.820–1.242)	0.931	0.937 (0.777–1.131)	0.497
SBP (mmHg)	1.001 (0.995–1.006)	0.781	0.997 (0.993–1.001)	0.206
DBP (mmHg)	1.002 (0.993–1.011)	0.614	0.995 (0.988–1.002)	0.179
HbA1c (%)	0.987 (0.903–1.080)	0.991	1.005 (0.935–1.131)	0.497
FBG (mmol/L)	1.000 (0.946–1.058)	0.931	1.023 (0.984–1.064)	0.254
TG (mmol/L)	1.042 (0.960–1.131)	0.323	0.937 (0.777–1.131)	0.497
TC (mmol/L)	1.062 (0.963–1.171)	0.232	1.076 (0.987–1.174)	0.096
HDL-C (mmol/L)	1.285 (0.938–1.759)	0.118	1.025 (0.940–1.118)	0.578
LDL-C (mmol/L)	1.085 (0.952–1.235)	0.221	1.189 (0.932–1.516)	0.163

Abbreviations: HR, hazard ratio; CI, confidence interval.
p-values were considered statistically significant at α = 0.05.

Table 4. Multivariate Cox regression analysis of factors influencing IVCF indwelling time.

Variable	HR	95% CI	p-value
Age (years)			
<60	Ref		
≥60	1.3	1.051–1.609	0.016
DVT Type			
AKDVT	Ref		
PVT	0.971	0.433–2.175	0.943
BKDVT	1.802	1.029–3.157	0.039
MDVT	1.065	0.597–1.903	0.831

p-values were considered statistically significant at α = 0.05.

ical insights. To the best of our knowledge, this is the first study to evaluate the factors influencing the indwelling time of retrievable IVCFs in patients with fractures that are complicated by DVT while comparing different DVT locations and filter models.

Our study was conducted between June 2017 and December 2021, a period marked by significant advancements in DVT management guidelines and IVCFs technology. The 2020 Chinese guidelines for IVCF usage restrict filter placement to patients with acute proximal DVT who have contraindications to anticoagulation and require thrombectomy within 12 weeks [37]. Meanwhile, the Society of Interventional Radiology (SIR) guidelines emphasize individualized retrieval windows. For example, ≤200 days for Denali filters and ≤2 weeks for Cordis filters [38]. In keeping with these evolving recommendations, our hospital adopted standardized search criteria based on annual guideline revisions to ensure consistent application of risk-benefit assessments. The introduction of the Denali filter enhanced tilt resistance, prolonged the safe indwelling time (≤200 days), and improved operational safety. Additionally, the advent of mechanical thrombectomy devices (e.g., AngioJet) in subsequent years has enabled more effective thrombus burden reduction, potentially reducing dependence on IVCFs [39,40].

Despite these technological and procedural advancements, all patients in our cohort were consistently managed with anticoagulation therapy and did not undergo thrombectomy to isolate the effects of filter type and thrombus location. Furthermore, IVCF implantation strictly followed the guidelines issued by the Society for Vascular Surgery of the Chinese Medical Association (3rd edition) to ensure consistent inclusion criteria (such as fracture surgery with proximal DVT), although the national guidelines have evolved. These measures helped minimize potential confounding due to temporal practice variations.

In this study, we observed that the indwelling time for the Denali group was longer than that in the Cordis group. In the Denali group, regardless of DVT location, the indwelling duration ranged from 42 to 67 days, which aligns with previous research that suggesting that the mean indwelling time of the Denali filter was 60.4 $\pm$ 7 days [11]. In contrast, the Cordis group exhibited shorter indwelling durations (15.5–21 days), aligning with earlier findings [41–43] that proposed a retrieval window of 12 days based on animal model experiments [41]. While Rimon *et al.* [42] recommended a 60-day limit for filter retention, reporting an average duration of 25 days, other researchers have observed mean indwelling times of 16 days or less [43]. We also identified significant differences in indwelling times among AKDVT, PVT, BKDVT, and MDVT groups within both the Denali and Cordis groups. To our knowledge, this study is novel in examining the relationship between DVT location and IVCF indwelling duration. Our findings indicate that AKDVT is more likely to result in thrombus formation ≥1 cm in the filter compared to BKDVT, while PVT shows a higher propensity to form thrombi <1 cm in size relative to AKDVT [22]. We propose that our results may provide a reference for future determinations of appropriate filter indwelling time.

Age has been previously identified as a significant factor that influences the formation of IVCF tilt, with older patients or those with multiple comorbidities being significantly less likely to have their filters retrieved [44]. A separate investigation into the retrieval and long-term outcomes among patients with IVCFs identified cancer, advanced age, and the presence of DVT as factors associated with increased mortality [45]. In our study, age was found to influence indwelling time in the Denali group but did not show a statistically significant effect in the Cordis group. This may be attributed to the higher proportion of elderly individuals in the Denali group (60.56%) compared to the relatively balanced age distribution in the Cordis group.

Hyperglycemia, hypertension, and dyslipidemia are recognized as risk factors for thrombosis-related conditions [46,47]. Diabetes has been shown to elevate the risk of DVT and PE [48], and it also contributes to the higher incidence of DVT following total knee arthroplasty [49]. To assess the influence of blood glucose, blood pressure, and blood lipid profiles on filter indwelling duration, we conducted relevant analyses and observed no significant differences in indwelling time associated with diabetes or hypertension in either the Denali or Cordis group.

Our study has several limitations that warrant acknowledgement. First, although all patients presented with lower extremity or pelvic fractures, specific fracture subtypes were not analyzed due to incomplete records (e.g., femoral vs. pelvic fractures) and lack of detailed information on the immobilization period. These variables are known to influence DVT risk and clinical management. For example, pelvic fractures are associated with a higher incidence of proximal DVT due to venous compression and may, therefore, require a longer IVCF indwelling time [17,50]. Similarly, prolonged immobilization may delay thrombus resolution, thereby extending the optimal retrieval window [51]. Nonetheless, our findings on the interaction between DVT location and filter type remain valid, as these relationships are independent of fracture subtypes [52]. Future studies should prospectively collect detailed data on fracture subtypes (for example, Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) classification) and immobilization protocols to refine risk stratification models and clinical decision-making.

Second, baseline coagulation characteristics (e.g., D-dimer and fibrinogen levels) and detailed anticoagulation regimens (e.g., drug type, dosage, and duration) were not systematically collected. These data are critical for the assessment of thrombotic risk and may influence decisions regarding IVCF placement and indwelling time [53]. For example, patients receiving long-term anticoagulation therapy such as rivaroxaban may experience accelerated thrombus resolution, thereby shortening the optimal window for safe thrombectomy [54]. In contrast, low-dose anticoagulation may prolong DVT stability and require a longer filter indwelling period [55]. Although our institution standardized perioperative anticoagulation using low-molecular-weight heparin (LMWH) for all fracture patients with DVT, individual variations in adherence or dose adjustments were not recorded. Future studies should integrate coagulation biomarkers and real-world anticoagulation data to refine risk stratification and guide optimal IVCF management. Despite these limitations, our findings on the interaction between DVT location and filter type remain robust, as these associations are independent of anticoagulant effects.

Although anticoagulant therapy and physical prophylaxis remain first-line strategies for DVT management, IVCFs continue to serve an irreplaceable role in specific high-risk populations [56]. In orthopedic patients with absolute contraindications to anticoagulation (such as active bleeding or recent intracranial surgery) or those at high perioperative risk for PE (such as with proximal free-floating thrombi), IVCFs provide immediate mechanical protection that does not rely on drug metabolism [57]. However, IVCFs are not without complications. Long-term indwelling may lead to filter-related thrombosis (21.4%), inferior vena cava perforation (7.5%) and other adverse outcomes [58–60], often necessitating a second intervention for removal and increasing the overall medical burden.

Conclusions

Pulmonary embolism constitutes a significant public health burden due to its associated morbidity and mortality. Although IVCFs are an effective strategy for preventing life-threatening PE in orthopedic surgery patients with DVT, determining the optimal monitoring period, considering thrombus location and filter type, is essential for establishing a rational timeframe for filter retention.

Availability of Data and Materials

The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

Author Contributions

GZW and WS were responsible for conceptualization, methodology, formal analysis, writing the original draft. HL and HG collected and analyzed the data and supervised the study. YL, ZSC, JXL and YJG were responsible for participant enrollment, data collection, software use and validation, and data visualization. FQC and JHY were responsible for designing the study and performing data analyses, reviewing, and editing the draft. All the authors contributed to the interpretation of the data and the critical revision of important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was approved by the Ethics Committee of Shenyang Orthopedic Hospital (Shenyang, China, 2022-KY-002-02). The written informed consent was obtained from all participants. This study was conducted in accordance with the principles outlined in the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

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