Celect Inferior Vena Cava Wall Strut Perforation Begets Additional Strut Perforation

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ABSTRACT

Purpose: To identify risk factors for strut perforation following Celect inferior vena cava (IVC) filter (IVCF) placement and to use finite element modeling to predict the mechanical impact of long-dwelling filters.

Materials and Methods: Ninety-one patients with three computed tomography (CT) studies were evaluated following Celect IVCF placement (2007–2013). Three-dimensional finite element models of the Celect IVCF were developed to simulate mechanical deformation of the IVCF encountered in vivo. Simulated forces applied by the primary struts on the IVC wall were measured as a function of luminal area and tilt angle.

Results: Although 33 patients (36%) showed primary strut perforation on initial follow-up CT, 60 patients (66%) showed progressive perforation over time ($P < .0001$), with 72 patients (79%) showing primary strut perforation on the final CT (average, 554 d). Female patients ($P = .004$) and those with malignancy history ($P = .01$) had significantly higher perforation rates at a given time. Caval area also decreased after primary filter strut perforation, and we therefore proposed that this was the mechanism for progressive perforation. Consistent with this mechanism, three-dimensional finite element modeling demonstrated increasing strut force with decreasing IVC diameter.

Conclusions: Celect IVCF primary strut perforation is progressive over time and is more common in female patients and those with a history of malignancy. In addition, this progressive perforation may be predicted by three-dimensional finite element modeling. These patient populations may require closer follow-up after IVCF placement to prevent or reduce the risk for filter complication or worsening perforation.

ABBREVIATIONS

IVC = inferior vena cava, IVCF = inferior vena cava filter, GLMM = generalized linear mixed model

The long-term complications of retrievable inferior vena cava (IVC) filters (IVCFs) include filter tilt, migration, strut perforation, erosion, and fracture, as well as recurrent pulmonary embolism and IVC thrombosis with lower-extremity edema (1–6). Although retrievable IVCFs are approved for permanent placement, the long-term sequelae associated with these filters are still surfacing. The literature remains largely dedicated to retrieval results rather than long-term follow-up. IVC perforation is a particularly common device complication of IVCFs recognized on follow-up computed tomography (CT) studies (7–9). In addition to the inherent risks associated with perforation to adjacent organs and device structural integrity (7–11), perforation may make filter retrieval challenging, which in turn may render a patient at a higher risk for procedural complication during retrieval with longer fluoroscopic times (12,13). The Celect retrievable IVCF (Cook, Bloomington, Indiana) demonstrates among the greatest variability in reported IVC perforation rates, ranging from 22% to 93% (7,8,14–18), although not reported for comparable time ranges following placement. The purpose of the present study was to evaluate the progressive, long-term

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changes following placement of Celect IVCFs on CT studies to identify at-risk populations for perforation, and develop a computer model to investigate the mechanical factors that may play a role in strut perforation.

MATERIALS AND METHODS

The present retrospective study was approved by our institutional review board with a waiver of informed consent.

Patients

The study included all patients at our institution who had an infrarenal Celect IVCF placed between January 1, 2007, and June 1, 2013, and had at least three follow-up abdominal CT studies. Patients were identified through departmental records and the medical records department. Patient demographics and clinical histories were obtained through our institution's electronic medical record. A total of 550 patients had Celect IVCFs placed during the study dates: 285 men and 265 women with an average overall age of 59 years ± 16, with 251 having a history of malignancy. Of these patients, the final study population included 91 patients who had at least three follow-up abdominal CT studies (**Table 1**). The filter could be evaluated on all included follow-up imaging studies.

Follow-up Imaging and Interpretation

Our institution's picture archiving and communication system (Agfa, Mortsel, Belgium) was searched for any available CT studies acquired during routine clinical care for any indication that showed the entire IVCF. A total of 273 CT studies from 91 patients were included and evaluated in the study. For patients with three or more follow-up studies, the earliest available study, the latest available study, and the median study between those dates were evaluated.

Table 1. Patient Demographic Data and Timing of CT Follow-up

Characteristic	Value
No. of patients	91
Age at filter placement (y)	
Mean	60
Range	18–85
Sex	
Male	47 (52)
Female	44 (48)
Malignancy history	
Yes	65 (71)
No	26 (29)
Average time to CT (d)*	
First CT	75
Range	0–777
Last CT	554
Range	26–1,371

Note–Values in parentheses are percentages.
*Times calculated from date of filter placement.

Each follow-up CT study was reviewed independently by two authors on picture archiving and communication system workstations to assess primary and secondary strut IVC perforation. IVC luminal area was manually traced along the IVC wall contours at the level of the filter strut feet. Any discrepancy between the assessments made on the initial independent review was adjudicated by the other authors. Perforation was defined in accordance with the Society of Interventional Radiology practice guidelines for IVCFs as a filter leg extending greater than 3 mm beyond the IVC wall (3). Additionally, the initial diameter of the infrarenal IVC before filter placement was measured on the venacavogram obtained immediately before filter placement as a potential risk factor for strut perforation.

Data Analysis and Computational Modeling

Detailed methods on data analysis and computational modeling are included in the **Appendix** (available online at *www.jvir.org*).

RESULTS

Perforation Rates

Our assessment clearly demonstrated a progressive trend of strut perforation over time. By the first follow-up CT study (mean follow-up, 75 d), perforation of at least one strut was observed in 36% of Celect filters (33 of 91). The perforation rate increased to 71% (65 of 91) by the second follow-up CT (mean follow-up, 316 d) and 79% (72 of 91) by the final follow-up CT (mean follow-up, 554 d; **Table 1**). Among the 33 filters that were perforated by the first follow-up CT examination, the number of perforated primary struts also increased from 2.5 ± 1.0 by the first follow-up to 3.2 ± 0.9 at the second follow-up and stayed at 3.2 ± 0.8 by the final follow-up. The majority of patients (n = 60; 66%) showed progressive primary strut perforation, defined as the presence of additional primary strut perforation noted on subsequent follow-up CT scans. In contrast, 19 patients (21%) showed no perforation on any studied follow-up CT scan, and 12 patients (13%) had primary strut perforation on follow-up CT without progression of perforation (**Appendix** [see **Results**] and **Fig E1**, available online at *www.jvir.org*).

Model Fitting

These findings suggested that primary strut perforation for Celect filters progressed over time. Therefore, we developed a generalized linear mixed model (GLMM) to test our hypothesis. To identify significant risk factors for strut perforation, patient sex, age at filter placement, malignancy history, and the initial size of the IVC were