Inferior Vena Cava Filtration in the Management of Venous Thromboembolism: Filtering the Data

Christopher Molvar, M.D.¹

¹Loyola University Medical Center, Maywood, Illinois

Semin Intervent Radiol 2012;29:204–217

Address for correspondence and reprint requests Christopher Molvar, M.D., Department of Radiology, Loyola University Medical Center, 2160 South First Ave., Maywood, IL 60153 (e-mail: cmolvar@LUMC.edu).

Abstract

Keywords

- inferior vena cava (IVC) filter
- venous thromboembolism
- deep vein thrombosis
- pulmonary embolism
- trauma
- complications

Venous thromboembolism (VTE) is a common cause of morbidity and mortality. This is especially true for hospitalized patients. Pulmonary embolism (PE) is the leading preventable cause of in-hospital mortality. The preferred method of both treatment and prophylaxis for VTE is anticoagulation. However, in a subset of patients, anticoagulation therapy is contraindicated or ineffective, and these patients often receive an inferior vena cava (IVC) filter. The sole purpose of an IVC filter is prevention of clinically significant PE. IVC filter usage has increased every year, most recently due to the availability of retrievable devices and a relaxation of thresholds for placement. Much of this recent growth has occurred in the trauma patient population given the high potential for VTE and frequent contraindication to anticoagulation. Retrievable filters, which strive to offer the benefits of permanent filters without time-sensitive complications, come with a new set of challenges including methods for filter follow-up and retrieval.

Objectives: Upon completion of this article, the reader will be able to identify the current state of knowledge and controversies regarding IVC filtration including types of filters, indications for filter placement, and retrieval including technical considerations and potential complications.

Accreditation: Tufts University School of Medicine is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians.

Credit: Tufts University School of Medicine designates this journal-based CME activity for a maximum of **1 AMA PRA Category 1 Credit™**. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Case History

A 45-year-old woman presented after a traumatic event with a splenic laceration and femoral fracture. The splenic laceration was managed conservatively with planned operative treatment of the femoral fracture. Her early hospital course

was complicated by left femoral acute deep venous thrombus documented by ultrasound. Systemic anticoagulation was contraindicated due to the planned orthopedic surgery and recent splenic laceration, and the patient was referred to interventional radiology for an inferior vena cava (IVC) filter placement. After discussion with the referring trauma surgery service, the decision was made to place a retrievable IVC filter given the patients anticipated short-term contraindication to anticoagulation, anticipated recovery to an ambulatory state, and lack of comorbid conditions in this middle-age patient.

After lidocaine local anesthesia and under ultrasound guidance, the right internal jugular vein was accessed with a 5F micropuncture kit. A guidewire was advanced into the infrarenal IVC under fluoroscopic visualization, and a 6F short vascular sheath was placed over the guidewire. A pigtail catheter was advanced to near the iliac venous confluence, and vena cavography was performed with 40 cc of nonionic contrast at a rate of 20 cc per second (► **Fig. 1A**). Venography demonstrated a normal caliber IVC, no intracaval thrombus, and no variant venous anatomy. In addition, review of trauma abdomen/pelvis computed tomography (CT) confirmed

Figure 1 A 45-year-old female trauma victim with contraindication to anticoagulation. (A) Preplacement vena cavogram with catheter placed via a right internal jugular vein approach. No intracaval thrombus or variant venous anatomy is present, and bilateral renal vein inflow is noted. (B) Technically successful infrarenal placement of a Celect inferior vena cava filter (Cook Medical Inc., Bloomington, IN). Case continues in Figs. 2 and 3.

normal venous anatomy. The pigtail catheter was removed over a guidewire, and the filter delivery sheath was advanced over the guidewire to the iliac venous confluence. Using fluoroscopic visualization, a Celect IVC filter (Cook Medical Inc., Bloomington, IN) was deployed in an infrarenal location (►Fig. 1B). This filter was placed within 3 hours of request, ~24 hours after patient admission.

The patient was seen in the institutional filter clinic ~2 months after IVC filter placement. At this point she was ambulating normally and was therapeutic on anticoagulation for at least 2 weeks. She was scheduled for IVC filter removal without interruption of her therapeutic anticoagulation.

The removal attempt was performed using ultrasound guidance. The right internal jugular vein was accessed with a 5F micropuncture kit following lidocaine local anesthesia. A guidewire was advanced into the IVC under fluoroscopic guidance. A 6F short vascular sheath was placed over the guidewire, and a pigtail catheter was advanced to the iliac venous confluence. Venacavogram (40 cc contrast at a rate of 20 cc per second) demonstrated trapped thrombus in the filter cone, occupying ~25% of the conical volume (►Fig. 2). The decision was made to leave the filter in place, with continued anticoagulation and repeat vena cavogram in 1 month. During this second procedure, 3 months after filter placement, a venacavogram showed resolution of the filter thrombus and no intracaval thrombus (►Fig. 3A). For the removal, coaxial sheaths were placed over a guidewire; specifically, a 10F outer sheath and a longer 7F inner sheath were used. Using a loop snare, the filter hook was engaged and readily collapsed into the 7F sheath with minimal resis-

tance (►Fig. 3B). The filter and 7F sheath were removed as a unit. Visual inspection showed the filter to be intact, and per institutional policy it was subsequently sent to surgical pathology for documentation.

Venous Thromboembolism

PE and deep vein thrombosis (DVT) are together known as venous thromboembolism (VTE). Approximately a third of the 38 million U.S. hospital discharges in 2003 were at risk for VTE, thus highlighting the magnitude of this public health concern.¹ VTE annually affects 1 to 2 individuals per 1000 in the United States, resulting in substantial morbidity and mortality.² Symptomatic VTE presents with DVT in about two thirds of patients with the remaining one third presenting with PE.³

The impact of VTE is most significant in hospitalized patients, with more than half of all cases occurring in this setting; this makes PE the leading preventable cause of in-hospital mortality.⁴ Approximately 300,000 people die from acute PE each year in the United States.⁵ In hospitalized trauma patients, the rate of PE approaches 22% with an estimated mortality of 8 to 35%.^{6,7} The cost per episode of PE is close to \$13,000, and additional costs are likely incurred with management of the DVT complication of postthrombotic syndrome (PTS).⁸

Pathophysiology of Venous Thromboembolism

Virchow elucidated the pathophysiology of VTE with a triad of important factors: stasis, venous intimal injury, and

Figure 2 Same patient as Fig. 1. Vena cavogram 2 months after inferior vena cava filter placement demonstrates trapped thrombus in the cone of the filter in two projections (arrows). (A) Anterior posterior and (B) oblique projection. Although trapped thrombus volume is ~25% of the filter conical volume, the decision was made to leave the filter in place with continued anticoagulation and repeat vena cavogram in 1 month. Case continues in Fig. 3.

Figure 3 Same patient as Figs. 1 and 2. (A) Follow-up vena cavogram 3 months after filter placement shows resolution of filter-trapped thrombus without intracaval thrombus. The inferior vena cava (IVC) filter was removed using a loop snare. (B) Image of filter with retrieval hook engaged by a loop snare as a jugular sheath is advanced, collapsing the filter. (C) Spot image documented complete removal of the IVC filter.

hypercoagulable state. This triad reflects the influence of both genetic and environmental risk factors on VTE. Thrombi commonly form in the deep veins of the calf and propagate into the proximal veins, from which they are more likely to embolize.⁵ Approximately 50% of patients with proximal DVT (popliteal and more central veins) develop PE.⁵

Most symptomatic PE originates in the deep veins of the thigh. Acute DVT is loosely adherent to the vein wall and may embolize resulting in PE. After 7 to 10 days, thrombus begins to adhere to the vein wall resulting in inflammatory changes.

These inflammatory changes damage venous valves, making them incompetent and prone to venous reflux.³ The clinical consequence of lower extremity venous reflux can be PTS, which occurs in about a third of patients with a history of DVT.^{1,9} Risk factors for PTS include recurrent ipsilateral DVT, lack of vein recanalization, increased body mass index, and inadequate anticoagulation therapy.^{10,11} There is no gold standard objective test for PTS, and as such it is diagnosed primarily on typical clinical signs and symptoms.¹² PTS is characterized by aching pain/heaviness on standing, pruritus,

dependent edema, and sometimes lipodermatosclerosis and venous ulcers. This chronic complication of VTE decreases quality of life and is associated with high long-term treatment costs. Based on research, the quality of life in patients with PTS is worse than similar age patients with arthritis, chronic lung disease, and diabetes.¹³

There are numerous clinical risk factors for VTE including trauma, major surgery, acute medical illness, cancer, genetic disorders, decreased mobility, pregnancy, estrogen therapy, obesity, atherosclerosis, and thrombophilic disorders.^{5,10} Some of these risks are transient, such as major surgery and trauma, whereas others are permanent. Studies estimate the risk of PE in cancer patients to be 3.6-fold higher than in patients without cancer,¹⁴ and this risk is heightened by cancer treatment such as chemotherapy.¹⁵ Patients with cancer account for 20% of patients with VTE,¹⁶ and active cancer is associated with a high risk of recurrent VTE.¹⁵ Individual evaluation of each patient for the presence of transient and/or long-term risk factors for VTE is paramount to selecting a treatment strategy.¹⁷

Treatment of Venous Thromboembolism

The preferred method of both treatment and prophylaxis for VTE is anticoagulation. The foundation of VTE therapy includes rapid initial anticoagulation to reduce the risk of clot propagation, long-term anticoagulation to reduce the risk of VTE recurrence, and discontinuation of anticoagulation when the risk of treatment exceeds the risk of recurrent VTE.¹⁸ Even with appropriate anticoagulation therapy, VTE recurrence is noted in ~7% of patients during the first 6 months, with most recurrences occurring within 3 months.³ For this reason, the typical duration of anticoagulation therapy is at least 3 months. Anticoagulation therapy is associated with a small but real risk of major hemorrhage (<5%).¹⁹ Most patients with acute PE who receive adequate anticoagulation therapy survive, with a 3-month overall mortality rate of ~15 to 18%.^{5,20} However, in a subset of patients, anticoagulation is contraindicated or ineffective. Treatment for these patients is often with an IVC filter for prevention of clinically significant PE.²¹

Inferior Vena Cava Filters

IVC filters were first introduced in the 1970s for prevention of PE. The Prevention du Risqué d'Embolie Pulmonaire par Interruption Cave (PREPIC) trial is the only randomized controlled trial to evaluate their effectiveness.²² In this trial, 400 patients with proximal DVT, at high risk for PE, were randomized to anticoagulation with a permanent IVC filter versus anticoagulation alone. Twelve days after randomization, the filter group had a statistically significant reduction of 78% in the risk of PE ($p = 0.03$). After two years, however, this PE risk reduction was no longer statistically significant, and there were significantly more recurrent DVTs in the filter group (20.8%) versus the no-filter group (11.6%; $p = 0.02$). In follow-up reporting at 8 years, there were significantly fewer symptomatic PEs in the filter group (6.2%) versus the no-filter group (15.1%; $p = 0.008$),²³ with significantly more symptomatic DVT in the filter group (35.7%) compared with the no-

filter group (25.5%; $p = 0.042$). No survival difference was present between the two patient groups at 12 days, 2 years, or 8 years; and interestingly, no difference in the prevalence of postthrombotic syndrome was reported. Because all patients in this trial received anticoagulation therapy, it provides little guidance in IVC filter placement in patients who cannot receive anticoagulation.

Similar results to the PREPIC trial were found in the Worcester population-based VTE observational study, which showed a nonstatistically significant lower rate of PE at 3 years for patients treated with an IVC filter (1.7%) compared with those without (5.3%; $p = 0.18$).²⁴ Similar to the results of the PREPIC study, the incidence of recurrent DVT was 21% for patients with an IVC filter and 14.9% for patients treated without a filter ($p = 0.009$). In a review by Carrier et al, the rate of recurrent PE in patients with VTE on anticoagulation therapy was 1.7% at 6 months, and the rate of major bleeding was 2.1%.²⁵ Importantly, no clinical trial directly compares the effectiveness of anticoagulation alone with IVC filters.

Inferior Vena Cava Filter Types

The two basic IVC filter types are permanent and nonpermanent. Permanent filters have been available for approximately the past 35 years. During this period, a large body of experience and published data were amassed regarding permanent filters. As with nonpermanent filters, most of these data are observational and retrospective, rather than randomized and prospective.¹⁷ Of 568 IVC filter studies evaluated in a recent literature review, two thirds were retrospective in design, and heterogeneity among prospective studies precluded any relevant comparison.²⁶ Moreover, there is no comparative study demonstrating superiority of the various modern filter designs.

Nonpermanent filters were developed to reduce the long-term complications of permanent filters, notably increased risk of DVT.²⁷ There are two primary subgroups of nonpermanent filters: temporary filters, which *must* be retrieved, and retrievable (or optional) filters, which *can* be retrieved. Temporary filters are tethered to the skin by a wire/catheter for short-interval retrieval; these filters are no longer commercially available in the United States. Retrievable filters seek to offer the benefits of permanent filters for a limited duration of time only; they also maintain the "option" to be left in situ as a permanent device because many designs were initially approved for permanent placement. There is a subtype of retrievable filters, namely convertible filters, which can be structurally altered after implantation to no longer function as filters. Therefore, the filter is not removed, but the filtering capacity is eliminated by a percutaneous catheter-based procedure.

Indications

The American College of Chest Physicians (ACCP) and American College of Radiology (ACR)/Society of Interventional Radiology (SIR) have each published evidence-based guidelines for the placement of IVC filters. Due to the paucity of such studies, these guidelines are not based on level 1 evidence (prospective randomized controlled trials). The

ACCP recommends placement of an IVC filter in patients with acute proximal DVT or PE if anticoagulant therapy is not possible because of the risk of bleeding.¹⁸ Specific contraindications to anticoagulation and definition of bleeding risks are not explicitly discussed, making interpretation of this guideline subjective.²⁴ Importantly, the ACCP does not recommend IVC filters as primary prophylaxis for any patient group. It is estimated that approximately half of all filters placed are consistent with these guidelines.²⁴

ACR/SIR (2010) practice guidelines divide indications for filter placement into therapeutic and prophylactic. Therapeutic guidelines mirror ACCP recommendations with several additions (►Table 1), including the failure of or inability to achieve/maintain adequate anticoagulation, free-floating central venous thrombus, massive PE with residual DVT, and severe cardiopulmonary disease with VTE. Prophylactic indications occur in patients without VTE but who are at increased risk of PE and cannot receive effective primary prophylaxis (i.e., anticoagulation, compression stockings). Prophylactic indications are often seen in the setting of severe trauma or prior to major surgery (►Table 1). SIR also recognizes indications for placement of retrievable filters; specifically, VTE with transient inability to anticoagulate, PE prophylaxis in high-risk patients, and caval filtration in children.

Relative Contraindications

Contraindication to IVC filter placement is rare: Uncorrectable severe coagulopathy and bacteremia are two specific relative contraindications. One investigation described filter use in septic patients and demonstrated the Greenfield filter to be safe and effective in the prevention of PE without documented filter implant infection.²⁸

Filter Usage

IVC filter usage has increased each year since their introduction. According to a population-based study by Spencer et al, about one in eight patients with documented VTE will receive

an IVC filter as part of early treatment.²⁴ Retrospective evaluation of the National Hospital Discharge Survey database showed an estimated 2000 filters were placed in 1979 compared with an estimated 49,000 filters in 1999, representing a nearly 25-fold increase.²⁹ In 2007, ~167,000 filters were placed, with an expected 259,000 in 2012.³⁰

The use of retrievable filters in the prophylactic setting is largely responsible for the overall increase in number of filters placed. In 1999, 19% of filters were placed for prophylaxis.²⁹ Today, prophylactic indications account for >50% of all filter placements.¹⁰ A study by Kim et al documented a dramatic shift toward the use of retrievable filters; 86.7% of filters placed in 2006 were retrievable versus 10.7% placed in 2002.³¹ It should be noted, however, that many of these retrievable design filters may have been placed for permanent filter indications. This shift toward retrievable filters together with a relaxation of thresholds for placement, including prophylaxis, is important in understanding the overall growth in the IVC filter market.

Placement Technique

IVC filter placement is performed in both an inpatient and outpatient setting with most filters placed in an inpatient setting due to active management of VTE.

The ACR-SIR practice guideline includes a detailed description of IVC filter placement. Vascular access for placement of the filter is commonly performed via the right femoral or right internal jugular vein. The IVC should be assessed, preferably with vena cavography, prior to filter placement; this allows evaluation of the diameter of infrarenal IVC, location and number of renal veins, IVC anomalies (e.g., duplication), and intrinsic IVC disease including caval thrombus or extrinsic compression (►Fig. 4). About 2% of the population have a duplicated IVC, and 0.5% have a left-sided IVC.³² If a patient has compromised renal function or an iodinated contrast allergy, preplacement imaging can be accomplished without iodinated contrast by using carbon dioxide gas with a high imaging frame rate. Prior cross-

Table 1 IVC Filter Placement Guideline

ACR/SIR Indications for IVC Filters
Therapeutic (documented VTE) <ul style="list-style-type: none"> • Patients with PE or IVC, iliac, or femoral-popliteal DVT and one or more of the following: <ol style="list-style-type: none"> 1. Absolute or relative contraindication to anticoagulation 2. Complication of anticoagulation 3. Failure of anticoagulation: recurrent PE despite adequate therapy, inability to achieve/maintain adequate anticoagulation, propagation/progression of DVT on therapeutic anticoagulation. • Massive PE with residual DVT in patients at risk for further PE. • Free-floating iliofemoral or IVC thrombus • Severe cardiopulmonary disease with DVT
Prophylactic (no current VTE) <ul style="list-style-type: none"> • Severe trauma <ol style="list-style-type: none"> 1. Closed head injury 2. Spinal cord injury 3. Multiple long bone or pelvic fractures • High-risk patients

ACR, American College of Radiology; SIR, Society of Interventional Radiology; IVC, inferior vena cava; VTE, venous thromboembolism; PE, pulmonary embolism; DVT, deep vein thrombosis.

Figure 4 A 92-year-old woman with metastatic pancreatic cancer with recent pulmonary embolism despite therapeutic anticoagulation. (A) Vena cavogram via right internal jugular vein approach demonstrates a large filling defect in the caudal aspect of the inferior vena cava (IVC) consistent with thrombus. No variant venous anatomy was present. (B) Technically successful placement of infrarenal Vena Tech IVC filter, cephalad to the caval thrombus.

sectional imaging studies should be evaluated to assess caval anatomy. The ideal location for a filter is the infrarenal IVC; the apex of the filter should be at or immediately caudal to the level of the lowest renal vein. This decreases the potential “dead space” between the filter and the renal veins, in case of IVC thrombosis. In specific patients, other target locations may be appropriate including the suprarenal IVC, iliac veins, and superior vena cava. According to ACR-SIR practice guidelines, technical success for percutaneous IVC filter placement should be at least 97%.

Filter Follow-Up

Due to the increasing use of retrievable IVC filters, dedicated methods for filter follow-up and potential retrieval are important. This was recognized by the U.S. Food and Drug Administration in issuing a medical device alert in August 2010 entitled “Removing Retrievable Inferior Vena Cava Filters: Initial Communication.” This alert acknowledged the rapid increasing use of IVC filters and a growing number of reported adverse events, stating that these adverse events “may be related to a retrievable filter remaining in the body for long periods of time, beyond the time when the risk of PE has subsided.” The alert recommended that implanting physicians and clinicians responsible for the ongoing care of patients consider IVC filter removal as soon as protection from PE is no longer required.³³

Primary therapy for treatment and prevention of VTE is pharmacological anticoagulation. Anticoagulation is proven to prevent thrombus propagation, thus limiting recurrent

DVT/PE, improving morality, and decreasing the likelihood of PTS.³⁴ Additional primary VTE prevention is achieved with external compression devices usually worn on the lower extremities. Patients with VTE and an indwelling IVC filter should begin primary therapy as soon as possible, under the direction of evidence-based guidelines, because the filter will not affect resolution of the existing VTE.¹⁷

In patients with IVC filters placed for prophylactic indications, primary VTE therapy should be used based on assessment of underlying risk factors, regardless of the presence of an IVC filter.¹⁷ In other words, presence of a filter does not change the need for, or duration of, anticoagulation. This assessment should occur frequently with the goal to begin pharmacological or mechanical VTE prophylaxis in a timely fashion.

A critical step in managing a patient with a retrievable IVC filter is the decision to remove it; clearly, this is not part of the decision tree for management of permanent filters. The basic criterion for filter retrieval is an acceptably low risk for PE because the only purpose of the filter is prevention of clinically significant PE. A SIR multidisciplinary consensus conference recommends the following criteria be met before discontinuing IVC filtration¹⁷:

1. An indication for a permanent filter is not currently present.
2. The risk of clinically significant PE is estimated to be acceptably low due to sustained primary treatment (therapy or prophylaxis), or change has occurred in clinical status.

3. The patient will not return to high risk of PE in the near future because of interruption of primary treatment or an anticipated change in clinical management or condition (e.g., discontinuing anticoagulation therapy for planned surgery).
4. Life expectancy of the patient is long enough that presumed benefits of filter removal can be realized. Patients not anticipated to survive >6 months are unlikely to benefit from filter retrieval.
5. The filter can be safely removed including suitable venous access.
6. The patient agrees to have the filter removed.

The SIR consensus conference also stratifies patients into those with VTE and those without VTE, and it makes specific recommendations for each subset. Patients with filters and VTE should be treated with several weeks of anticoagulation prior to removal because symptomatic PE is most likely to occur within the first 2 to 3 weeks after diagnosis of VTE.³⁵ The presence of a filter should not alter the intensity or duration of anticoagulation.¹⁷ In a study by Ortega et al, they found no adverse events due to lack of anticoagulation in patients with indwelling permanent filters at 3- to 60-month follow-up.³⁶ Greenfield and Michna report a 98% caval patency rate after filter placement, over an average follow-up of 43 months, independent of anticoagulation.³⁷ Finally, a systematic review by Ray and Prochazka demonstrated a minimal and not statistically significant decrease in the incidence of VTE rates in subjects receiving anticoagulation after filter placement compared with those not receiving anticoagulation (12.3% versus 15.8%, respectively).³⁸

Patients with filters placed for prophylactic indications should be treated with primary prophylaxis, in a timely fashion, according to management guidelines. Only after initiation of primary prophylaxis or the risk of clinically significant PE has abated should filter removal occur in accordance with the SIR consensus conference. Also, there should be no evidence of interval development of VTE, and patients should undergo screening lower extremity duplex prior to filter removal. If interval VTE is diagnosed, then primary therapy should be instituted prior to filter removal.¹⁷

Pre-Retrieval Evaluation

A focused pre-retrieval history and physical examination are important to assess for clinical signs of VTE, along with failure or complications of primary VTE therapy/prophylaxis. Patients on anticoagulation should have laboratory assessment of coagulation parameters, and all patients should have a recent assessment of renal function. Stable patients, with documented VTE on therapeutic anticoagulation, do not need routine imaging of the lower extremity or pulmonary arteries prior to filter removal.¹⁷ As mentioned previously, patients with a prophylactic filter should be assessed with lower extremity venous duplex prior to filter removal; if DVT is discovered, filter removal should be delayed until initiation of primary VTE therapy, preferably with therapeutic anticoagulation for 2 to 3 weeks. Conversely, in this situation the filter can become a permanent device.¹⁷

According to SIR consensus guidelines, the consent process for removal of a retrievable filter should include the following: rationale for filter removal, possibility of failed retrieval, and voluntary nature of discontinuing caval filtration.

Technique for Inferior Vena Cava Filter Removal

Discontinuation of therapeutic anticoagulation is not required for IVC filter removal. A study by Hoppe et al demonstrates that filter retrieval in patients therapeutic on anticoagulation (including both oral anticoagulation and low molecular weight heparin) is safe and without increased risk of hemorrhagic complications at the access site or at the filter implantation site.³⁹ In a separate study, Rosenthal et al reported uneventful retrieval of 66 caval filters after initiation of anticoagulation therapy.⁴⁰

Internal jugular vein access is achieved with ultrasound guidance after administration of local lidocaine anesthesia, although retrieval of certain filter types is performed via the common femoral vein. Under fluoroscopic guidance, a flush catheter is advanced to the level of the iliac vein confluence. Digital subtraction caval imaging is preferentially performed with the use of iodinated contrast unless the patient has compromised renal function, in which case imaging can be accomplished with carbon dioxide gas. If the IVC and filter are free of thrombus, the retrieval procedure continues. If thrombus is detected in a filter placed for prophylaxis without known VTE, a new diagnosis of VTE is made, and primary therapy should be initiated; filter retrieval can be considered at a later date. Filters with thrombus occupying <25% of the conical volume in patients with known VTE are usually removed.^{41,42} Trapped thrombus >25% of the cone volume typically necessitates starting/continuing anticoagulation for several weeks before retrieval (►Fig. 5). Notably, trapped thrombus in the filter cone is more often detected in devices with a short dwell time.⁴³ Finally, caval thrombus detected above an indwelling filter often necessitates placement of an additional filter above the clot.

Routine filter retrieval involves engaging the device, usually with a snare around the retrieval hook, and collapsing the filter into a sheath. Coaxial sheaths can be used to increase inline filter collapsing forces and to prevent injury at the access site by protruding filter struts. The filter should be visually inspected after removal to ensure removal in its entirety, and at some institutions the device is sent to surgical pathology for documentation. If the filter is incompletely removed, imaging evaluation is undertaken to locate the missing pieces. There are no universally accepted guidelines for management of retained filter elements, and retroperitoneal and intrapulmonary fragments are rarely symptomatic. Fragments in the heart should be evaluated in consultation with a cardiac specialist (►Fig. 6-8).¹⁷

There are a variety of retrieval techniques for difficult IVC filters. These filters are often tilted with longer dwell times, which makes standard engagement of the device challenging. Several techniques of varying complexity to remove difficult filters are detailed by Van Ha et al.⁴⁴ Postretrieval caval imaging is recommended after difficult or prolonged procedures or if the patient reports pain during retrieval. Findings

Figure 5 A 28-year-old man with low back pain and factor V Leiden deficiency with history of venous thromboembolism. Preoperative placement of a Recovery inferior vena cava (IVC) filter (Bard, Tempe, AZ) was performed. In the postoperative period with the patient ambulatory and therapeutic on anticoagulation, IVC filter removal was attempted. (A) Vena cavogram with pigtail catheter placed via a right internal jugular vein approach shows large nonocclusive thrombus trapped in the interstices of the filter. Anticoagulation was continued with attempted filter retrieval in 1 month. (B) A 1-month follow-up vena cavogram in an oblique projection demonstrates resolution of filter trapped thrombus and no intracaval thrombus. As such, the filter was removed. (C) Postretrieval vena cavogram demonstrates normal caliber IVC without complication.

compatible with caval injury include contrast extravasation (►Fig. 9) and intimal irregularity (►Fig. 8D). There are no established management guidelines for these findings; however, these patients should be followed closely with consideration of repeat vena cavogram after several minutes, serial hemoglobin checks, and CT to document hemorrhage. Caval stenosis after filter removal is reported in ~6% of patients and may represent spasm or scarring (►Fig. 8D).⁴²

Improving Filter Retrieval

Up to 70% of retrievable filters are never removed.⁴⁵ Although some filters are not removed due to technical reasons (tilting, trapped thrombus), many patients are lost to follow-up. In a recent review by Angel et al, the mean retrieval rate was 34% with an average time to retrieval of 72 days.⁴ The most common reasons for not removing a retrievable filter were loss to follow-up and continued risk of PE.

Minochoa et al published results of a dedicated IVC filter clinic on optional filter retrieval rates.⁴⁶ All optional filters were placed with the intention of retrieval. After program establishment, the results of the next 100 retrievable filters were prospectively followed and compared with retrospective results of the past 9 years. A nurse coordinator and interventional radiologist conducted a medical record review beginning 2 to 3 weeks after filter placement. In collaboration with the referring physician, a decision was made to remove the device, continue to monitor it, or declare it permanent. After establishment of a filter clinic, the retrieval rate increased from 29% to 60% ($p < 0.001$). The mean time to retrieval in the postclinic group was 1.5 months.

More recently, Lynch reported a different methodology for following a large group of patients with retrievable IVC filters.⁴⁷ Appropriate candidates for device retrieval based on medical record review were contacted by mail every 1 to 3 months until successful removal, or until a total of four letters went unanswered and the patient was deemed lost to follow-up. Retrieval rates were compared with institutional historical data during which no structured follow-up existed. The structured program yielded a 59% retrieval rate compared to 24% with lack of dedicated follow-up ($p < 0.001$). The median filter dwell time was 224 days during the period of prospective follow-up with technical failed retrieval in only 1.3%. Other authors have described other schemes to improve the follow-up care for patients with retrievable devices.⁴⁸

Underlying the importance of expeditious retrievable filter tracking is the time-sensitive likelihood of removal. According to Angel et al, technically successful filter removal was achieved with the following rates: 99% at 1 month after placement, 94% at 3 months, and 37% at 12 months.⁴ The most frequent reasons for failed retrieval attempts were tilting of the filter and adherence of the filter to the caval wall. As mentioned earlier, a wide variety of techniques can be applied to aid in the removal of difficult filters.

Filter Complications

Complications associated with IVC filters include both periprocedural and longer term complications. Periprocedural complications are rare and largely avoided by using imaging guidance for each step of filter placement. In a study by Ray et al of 197 retrievable filters, there were no clinically evident complications related to filter insertion or retrieval.⁴⁹ The

Figure 6 A 52-year-old woman with prophylactic Recovery filter (Bard, Tempe, AZ), placed prior to spinal surgery; the patient developed chest pain several months after surgery. (A) Coronary angiogram with intracardiac inferior vena cava filter strut (arrow). (B) Left ventriculogram with additional filter strut in the right lung (arrow). The patient underwent operative removal of intracardiac filter strut with resolution of chest pain. Patient was then scheduled for IVC filter retrieval. Case continues in Figs. 7 and 8. Case courtesy of Marc Borge, MD.

Figure 7 Same patient as Fig. 6. (A) Spot image prior to retrieval procedure shows filter with missing primary struts, along with an additional displaced strut (arrow). (B) Vena cavogram via a right common femoral approach demonstrates an intracaval location of a displaced strut (arrow). (C) Displaced strut is engaged with a loop snare and (D) pulled free from Recovery filter. Case continues in Fig. 8. Case courtesy of Marc Borge, MD.

Figure 8 Same patient as Figs. 6 and 7. (A) Spot image showing snared filter strut and intrapulmonary strut (arrow). (B, C) Recovery cone is seen engaging the filter and then collapsing it into a jugular sheath. (D) Postretrieval venogram demonstrates irregular narrowing at site of previous filter consistent with spasm and/or scarring. Case courtesy of Marc Borge, MD.

complication rates of permanent and retrievable filters were comparable with similar clinical performance in prevention of PE in retrospective reviews.^{31,42} ► **Table 2** summarizes several major periprocedural complications (adapted from ACR-SIR Practice Guideline for the Performance of Inferior Vena Cava (IVC) Filter Placement for the Prevention of Pulmonary Embolism).¹⁷

Through a systematic review of the literature and the Manufacturer and User Facility Device Experience (MAUDE) database, Angel et al summarized the most common complications associated with the use of retrievable IVC filters.⁴ There were no reports of any major procedural complications during placement. The rate of DVT was 5.4% over a mean

follow-up of 9.9 months; however, reporting of this complication was variable. Significant filter migration, defined as migration >2 cm from placement location or filter embolization (e.g., heart, lungs), occurred in 1.3% of filters, with the highest incidence (4.5%) in the G2 filter. Most of these migration incidents occurred >30 days after placement. Filter fracture rates were not consistently reported in the literature; however, in the MAUDE database most reported events occurred with the G2 filter. In a review by Strieff, the filter fracture rate was 2.7% (► **Fig. 10**), and the incidence of vena cava thrombosis or stenosis was 2.8%.⁵⁰ Possible sequela of caval thrombosis includes phlegmasia cerulea dolens, increased risk of PTS, and recurrent PE due to thrombus that

Figure 9 Indwelling Günther Tulip inferior vena cava (IVC) filter (Cook Medical Inc., Bloomington, IN) is present in a patient therapeutic on anticoagulation. (A) Vena cavogram via a right internal jugular vein approach demonstrates an infrarenal filter with several struts projected minimally outside the contrast-opacified IVC. No intracaval thrombus or filter-trapped thrombus is noted. The filter was successfully removed. (B) Postremoval vena cavogram demonstrates contrast extravasation (arrow) at the level of previous filter-protruding struts. The patient was asymptomatic and vital signs were stable. (C) Resolution of contrast extravasation on 10-minute delayed vena cavogram.

extends cranial to a filter. The etiology of caval thrombus is uncertain and may be due to trapped thrombus or in situ thrombosis of the filter.⁵¹ As mentioned earlier, the use of anticoagulation after filter placement does not significantly influence caval patency.^{37,38}

Filter perforation, defined as visualization of filter elements >3 mm beyond the lumen of the IVC or within an adjacent structure, has not been systematically reported in the literature.⁴ However, 20% of the complications reported in the MAUDE database were perforations; in addition, Stawicki et al reported the rate of clinically significant penetration to be 0.4%.⁵²

Trauma

Trauma patients are at high risk for VTE due to endothelial damage, hypercoagulability from activation of acute-phase proteins, and prolonged immobility because these components fulfill Virchow's triad. PE is the cause of death in 20% of severely injured patients, making it the third most common cause of death in trauma patients who survive the initial 24 hours.^{53–55} VTE risk is 32% to 58%, depending on the extent of injury and use of prophylaxis.^{56,57} Those at highest risk include (1) severe head injury and coma, (2) spinal cord injuries with neurological deficit, and (3) pelvic and long bone fractures.⁵⁸ Furthermore, these high-risk patients often

carry contraindications to anticoagulation and/or mechanical compression devices.

Prophylactic placement of an IVC filter is increasing utilized in the trauma patient population. A retrospective review by Carlin et al documented an increase in prophylactic filter

Figure 10 An 80-year-old woman status post spinal surgery and kyphoplasty. Fractured indwelling TrapEase filter (Cordis, Bridgewater, NJ) is seen on lumbar spine radiograph. The patient was asymptomatic.

Table 2 Reported Inferior Vena Cava Filter Complication Rates

Complication	Reported Rates (%)	Threshold (%)
Death	0.12	<1
Filter embolization	0.1	1
Filter malposition	1–9	0
Access site occlusive thrombosis	3–10	3

placement in trauma patients from 3% (1991 to 1996) to 57% (1996 to 2001).⁵⁹ Several factors underlie this increased use; namely, the high rate of VTE in trauma patients, the ineffectiveness of low-dose heparin or compression devices, and concern among trauma specialists about bleeding complications associated with more potent pharmacoprophylactic methods.⁶⁰ The development of retrievable filters further spurred utilization because the risk of PE in the trauma population is usually time limited. In other words, retrievable IVC filters offer protection from PE during the posttraumatic period of greatest risk, and subsequent removal of the filter presumably eliminates the chance of long-term filter-related complications. Karmy-Jones et al further expounded on this concept in a multicenter study on practice patterns and outcomes of retrievable IVC filters in trauma patients.⁶¹ Specifically, three assumptions lead to increased retrievable filter placement in the trauma patients: (1) retrievable filters are as effective as permanent filters in preventing PE, (2) retrievable filters may be removed, and (3) long-term stability of retrievable filters, if left in situ, are equivalent to permanent filters. This study found that only 22% of retrievable filters were successfully removed, with loss to follow-up (31%) as the most common reason these devices were left in situ. However, if the service placing the filter had the primary responsibility for tracking it, loss to follow-up occurred in only 6% of patients.⁶¹

Greenfield et al examined the effectiveness of prophylactic IVC filter placement in trauma patients.⁶² In this prospective study, 249 patients had prophylactic filters placed. The rate of new PE was 1.5%, and the caval occlusion rate was 3.5%. The authors concluded that prophylactic filter placement is associated with a low incidence of adverse outcomes while providing protection from fatal PE. In an earlier publication, prophylactic filter placement in trauma patients decreased PE-related mortality and overall mortality.⁶³ Another study by Wojcik et al reported a series of 105 trauma victims who received permanent IVC filters in the setting of known VTE or VTE prophylaxis.⁶⁴ There were no documented PEs in patients with filters, but ~44% of the prophylactic patient cohort developed DVT after filter placement. Hoff et al reported on the use of a retrievable filter, the Günther Tulip filter (Cook), in the trauma population.⁶⁵ The device was considered for patients at high clinical risk for VTE with a contraindication to anticoagulation and/or pneumatic compression. There was no technical complication of filter placement and no documented in-hospital PE after initiation of IVC filtration. The decision to retrieve the filter was based on the change in VTE risk status (i.e., ambulatory), safety of anticoagulation, and the ability to use pneumatic compression devices. A total of 51% of filters were removed with no procedural complication. The authors concluded that retrievable filters are safe and effective without the potential long-term complications of permanent filters.

The Eastern Association for the Surgery of Trauma states that no level I studies exist to support insertion of IVC filters in trauma patients without a diagnosis of DVT or PE.⁶⁶ Still, they recommend consideration of prophylactic IVC filter insertion in patients who meet high-risk criteria and cannot be anticoagulated.

To address this lack of level I data, SIR convened a multidisciplinary research consensus panel to develop an agenda for IVC filter research.¹⁰ The consensus priority was a randomized controlled trial of prophylactic vena cava filters in trauma patients. Several advantages of this topic were explained including prevention of clinically important PE in a high-risk population that currently receives a large proportion of filters.

Summary

PE is the leading preventable cause of in-hospital mortality. First-line therapy and prophylaxis for VTE is anticoagulation. In a subset of patients, anticoagulation therapy is contraindicated or ineffective and IVC filter placement is considered. The only purpose of IVC filters is the prevention of clinically significant PE. This simple function is met with conflicting recommendations for placement by the ACCP and ACR/SIR because guiding randomized controlled data are lacking. Observational studies and consensus opinion, along with the introduction of retrievable filters, has led to increased utilization of IVC filtration. The retrievable filter, which strives to offer the benefits of permanent filters without their long-term complications, has introduced new challenges including methods of filter follow-up and retrieval. New research indicates that dedicated methods of filter tracking improve retrieval rates and thus presumably limit time-sensitive complications, which is paramount given the expanded use of prophylactic filters. Further high-quality research is clearly needed to elucidate the appropriate role IVC filters in the treatment of VTE.

References

- 1 Anderson FA Jr, Zayaruzny M, Heit JA, Fidan D, Cohen AT. Estimated annual numbers of US acute-care hospital patients at risk for venous thromboembolism. *Am J Hematol* 2007;82(9):777-782
- 2 Tsai AW, Cushman M, Rosamond WD, Heckbert SR, Polak JF, Folsom AR. Cardiovascular risk factors and venous thromboembolism incidence: the longitudinal investigation of thromboembolism etiology. *Arch Intern Med* 2002;162(10):1182-1189
- 3 Kinney TB. Inferior vena cava filters. *Semin Intervent Radiol* 2006;23(3):230-239
- 4 Angel LF, Tapson V, Galgon RE, Restrepo MI, Kaufman J. Systematic review of the use of retrievable inferior vena cava filters. *J Vasc Interv Radiol* 2011;22(11):1522-1530, e3
- 5 Tapson VF. Acute pulmonary embolism. *N Engl J Med* 2008;358(10):1037-1052
- 6 Kudsk KA, Fabian TC, Baum S, Gold RE, Mangiante E, Voeller G. Silent deep vein thrombosis in immobilized multiple trauma patients. *Am J Surg* 1989;158(6):515-519
- 7 Cipolle MD, Wojcik R, Seislove E, Wasser TE, Pasquale MD. The role of surveillance duplex scanning in preventing venous thromboembolism in trauma patients. *J Trauma* 2002;52(3):453-462
- 8 Heck CA, Brown CR, Richardson WJ. Venous thromboembolism in spine surgery. *J Am Acad Orthop Surg* 2008;16(11):656-664
- 9 Prandoni P, Lensing AW, Cogo A, et al. The long-term clinical course of acute deep venous thrombosis. *Ann Intern Med* 1996;125(1):1-7
- 10 Kaufman JA, Rundback JH, Kee ST, et al. Development of a research agenda for inferior vena cava filters: proceedings from a multidisciplinary research consensus panel. *J Vasc Interv Radiol* 2009;20(6):697-707

- 11 Prandoni P, Kahn SR. Post-thrombotic syndrome: prevalence, prognostication and need for progress. *Br J Haematol* 2009; 145(3):286–295
- 12 Kahn SR, Partsch H, Vedantham S, Prandoni P, Kearon C; Subcommittee on Control of Anticoagulation of the Scientific and Standardization Committee of the International Society on Thrombosis and Haemostasis. Definition of post-thrombotic syndrome of the leg for use in clinical investigations: a recommendation for standardization. *J Thromb Haemost* 2009;7(5):879–883
- 13 Kahn SR, Ducruet T, Lamping DL, et al. Prospective evaluation of health-related quality of life in patients with deep venous thrombosis. *Arch Intern Med* 2005;165(10):1173–1178
- 14 Prandoni P, Lensing AW, Piccoli A, et al. Recurrent venous thromboembolism and bleeding complications during anticoagulant treatment in patients with cancer and venous thrombosis. *Blood* 2002;100(10):3484–3488
- 15 Blom JW, Doggen CJ, Osanto S, Rosendaal FR. Malignancies, prothrombotic mutations, and the risk of venous thrombosis. *JAMA* 2005;293(6):715–722
- 16 Hillen HF. Thrombosis in cancer patients. *Ann Oncol* 2000;(11 Suppl 3):273–276
- 17 Kaufman JA, Kinney TB, Streiff MB, et al. Guidelines for the use of retrievable and convertible vena cava filters: report from the Society of Interventional Radiology multidisciplinary consensus conference. *J Vasc Interv Radiol* 2006;17(3):449–459
- 18 Kearon C, Kahn SR, Agnelli G, Goldhaber S, Raskob GE, Comerota AJ. Antithrombotic therapy for venous thromboembolic disease: American College of Chest Physicians Evidence Based Clinical Practice Guidelines (8th Edition). *Chest* 2008;133(6, Suppl): 454S–545S
- 19 Levine MN, Raskob G, Landefeld S, Kearon C. Hemorrhagic complications of anticoagulant treatment. *Chest* 1998;114(5, Suppl): 511S–523S
- 20 Goldhaber SZ, Visani L, De Rosa M. Acute pulmonary embolism: clinical outcomes in the International Cooperative Pulmonary Embolism Registry (ICOPER). *Lancet* 1999;353(9162): 1386–1389
- 21 Kinney TB. Update on inferior vena cava filters. *J Vasc Interv Radiol* 2003;14(4):425–440
- 22 Decousus H, Leizorovicz A, Parent F, et al. A clinical trial of vena caval filters in the prevention of pulmonary embolism in patients with proximal deep-vein thrombosis. *Prévention du Risque d'Embolie Pulmonaire par Interruption Cave Study Group. N Engl J Med* 1998;338(7):409–415
- 23 PREPIC Study Group. Eight-year follow-up of patients with permanent vena cava filters in the prevention of pulmonary embolism: the PREPIC (Prevention du Risque d'Embolie Pulmonaire par Interruption Cave) randomized study. *Circulation* 2005;112(3): 416–422
- 24 Spencer FA, Bates SM, Goldberg RJ, et al. A population-based study of inferior vena cava filters in patients with acute venous thromboembolism. *Arch Intern Med* 2010;170(16):1456–1462
- 25 Carrier M, Le Gal G, Wells PS, Rodger MA. Systematic review: case-fatality rates of recurrent venous thromboembolism and major bleeding events among patients treated for venous thromboembolism. *Ann Intern Med* 2010;152(9):578–589
- 26 Girard P, Stern JB, Parent F. Medical literature and vena cava filters: so far so weak. *Chest* 2002;122(3):963–967
- 27 Imberti D, Prisco D. Retrievable vena cava filters: key considerations. *Thromb Res* 2008;122(4):442–449
- 28 Greenfield LJ, Proctor MC. Vena caval filter use in patients with sepsis: results in 175 patients. *Arch Surg* 2003;138(11): 1245–1248
- 29 Stein PD, Kayali F, Olson RE. Twenty-one-year trends in the use of inferior vena cava filters. *Arch Intern Med* 2004;164(14):1541–1545
- 30 Smouse B, Johar A. Is market growth of vena cava filters justified? *Endovascular Today* 2010:74–77
- 31 Kim HS, Young MJ, Narayan AK, Hong K, Liddell RP, Streiff MB. A comparison of clinical outcomes with retrievable and permanent inferior vena cava filters. *J Vasc Interv Radiol* 2008;19(3):393–399
- 32 Athanasoulis CA, Kaufman JA, Halpern EF, Waltman AC, Geller SC, Fan CM. Inferior vena caval filters: review of a 26-year single-center clinical experience. *Radiology* 2000;216(1):54–66
- 33 Administration USFaD. Removing retrievable inferior vena cava filters: initial communication. Available at: <http://www.fda.gov/MedicalDevices/Safety/AlertsandNotices/ucm221676.htm>. Posted August 9, 2010
- 34 Barnes RWEJ. Is anticoagulation justified following inferior vena cava filter placement? [abstract]. *Proc Intl Soc Cardiovasc Surg* 1994:558
- 35 Douketis JD, Foster GA, Crowther MA, Prins MH, Ginsberg JS. Clinical risk factors and timing of recurrent venous thromboembolism during the initial 3 months of anticoagulant therapy. *Arch Intern Med* 2000;160(22):3431–3436
- 36 Ortega M, Gahtan V, Roberts A, Matsumoto T, Kerstein M. Efficacy of anticoagulation post-inferior vena caval filter placement. *Am Surg* 1998;64(5):419–423
- 37 Greenfield LJ, Michna BA. Twelve-year clinical experience with the Greenfield vena caval filter. *Surgery* 1988;104(4):706–712
- 38 Ray CE Jr, Prochazka A. The need for anticoagulation following inferior vena cava filter placement: systematic review. *Cardiovasc Intervent Radiol* 2008;31(2):316–324
- 39 Hoppe H, Kaufman JA, Barton RE, et al. Safety of inferior vena cava filter retrieval in anticoagulated patients. *Chest* 2007;132(1): 31–36
- 40 Rosenthal D, Wellons ED, Lai KM, Bikk A, Henderson VJ. Retrievable inferior vena cava filters: initial clinical results. *Ann Vasc Surg* 2006;20(1):157–165
- 41 Rosenthal D, Wellons ED, Hancock SM, Burkett AB. Retrievability of the Günther Tulip vena cava filter after dwell times longer than 180 days in patients with multiple trauma. *J Endovasc Ther* 2007;14(3):406–410
- 42 Van Ha TG, Chien AS, Funaki BS, et al. Use of retrievable compared to permanent inferior vena cava filters: a single-institution experience. *Cardiovasc Intervent Radiol* 2008;31(2):308–315
- 43 Binkert CA, Morash MC, Gates JD. Venographic findings at retrieval of inferior vena cava filters. *AJR Am J Roentgenol* 2007;188(4):1039–1043
- 44 Van Ha TG, Vinokur O, Lorenz J, et al. Techniques used for difficult retrievals of the Günther Tulip inferior vena cava filter: experience in 32 patients. *J Vasc Interv Radiol* 2009;20(1):92–99
- 45 Grande WJ, Trerotola SO, Reilly PM, et al. Experience with the recovery filter as a retrievable inferior vena cava filter. *J Vasc Interv Radiol* 2005;16(9):1189–1193
- 46 Minocha J, Idakoji I, Riaz A, et al. Improving inferior vena cava filter retrieval rates: impact of a dedicated inferior vena cava filter clinic. *J Vasc Interv Radiol* 2010;21(12):1847–1851
- 47 Lynch FC. A method for following patients with retrievable inferior vena cava filters: results and lessons learned from the first 1,100 patients. *J Vasc Interv Radiol* 2011;22(11):1507–1512
- 48 Goei AD, Josephs SC, Kinney TB, Ray CE Jr, Sacks D. Improving the tracking and removal of retrievable inferior vena cava filters. *Semin Intervent Radiol* 2011;28(1):118–127
- 49 Ray CE Jr, Mitchell E, Zipser S, Kao EY, Brown CF, Moneta GL. Outcomes with retrievable inferior vena cava filters: a multicenter study. *J Vasc Interv Radiol* 2006;17(10):1595–1604
- 50 Streiff MB. Vena caval filters: a review for intensive care specialists. *J Intensive Care Med* 2003;18(2):59–79
- 51 Hann CL, Streiff MB. The role of vena caval filters in the management of venous thromboembolism. *Blood Rev* 2005;19(4):179–202
- 52 Stawicki SP, Sims CA, Sharma R, et al. Vena cava filters: a synopsis of complications and related topics. *J Vasc Access* 2008;9(2):102–110
- 53 Sevitt S. Fatal road accidents. Injuries, complications, and causes of death in 250 subjects. *Br J Surg* 1968;55(7):481–505

- 54 Knudson MM, Ikossi DG. Venous thromboembolism after trauma. *Curr Opin Crit Care* 2004;10(6):539–548
- 55 Anaya DA, Nathens AB. Thrombosis and coagulation: deep vein thrombosis and pulmonary embolism prophylaxis. *Surg Clin North Am* 2005;85(6):1163–1177, ix–x
- 56 Weinmann EE, Salzman EW. Deep-vein thrombosis. *N Engl J Med* 1994;331(24):1630–1641
- 57 Geerts WH, Jay RM, Code KI, et al. A comparison of low-dose heparin with low-molecular-weight heparin as prophylaxis against venous thromboembolism after major trauma. *N Engl J Med* 1996;335(10):701–707
- 58 Rogers FB, Shackford SR, Wilson J, Ricci MA, Morris CS. Prophylactic vena cava filter insertion in severely injured trauma patients: indications and preliminary results. *J Trauma* 1993;35(4):637–641; discussion 641–642
- 59 Carlin AM, Tyburski JG, Wilson RF, Steffes C. Prophylactic and therapeutic inferior vena cava filters to prevent pulmonary emboli in trauma patients. *Arch Surg* 2002;137(5):521–525; discussion 525–527
- 60 Devlin JW, Tyburski JG, Moed B. Implementation and evaluation of guidelines for use of enoxaparin as deep vein thrombosis prophylaxis after major trauma. *Pharmacotherapy* 2001;21(6):740–747
- 61 Karmy-Jones R, Jurkovich GJ, Velmahos GC, et al. Practice patterns and outcomes of retrievable vena cava filters in trauma patients: an AAST multicenter study. *J Trauma* 2007;62(1):17–24, discussion 24–25
- 62 Greenfield LJ, Proctor MC, Michaels AJ, Taheri PA. Prophylactic vena caval filters in trauma: the rest of the story. *J Vasc Surg* 2000;32:490–495; discussion 496–497
- 63 Rodriguez JL, Lopez JM, Proctor MC, et al. Early placement of prophylactic vena caval filters in injured patients at high risk for pulmonary embolism. *J Trauma* 1996;40(5):797–802; discussion 802–804
- 64 Wojcik R, Cipolle MD, Fearen I, Jaffe J, Newcomb J, Pasquale MD. Long-term follow-up of trauma patients with a vena caval filter. *J Trauma* 2000;49(5):839–843
- 65 Hoff WS, Hoey BA, Wainwright GA, et al. Early experience with retrievable inferior vena cava filters in high-risk trauma patients. *J Am Coll Surg* 2004;199(6):869–874
- 66 Rogers FB, Cipolle MD, Velmahos G, Rozycki G, Luchette FA. Practice management guidelines for the prevention of venous thromboembolism in trauma patients: the EAST practice management guidelines work group. *J Trauma* 2002;53(1):142–164