

Guidelines for the Use of Retrievable and Convertible Vena Cava Filters: Report from the Society of Interventional Radiology Multidisciplinary Consensus Conference

John A. Kaufman, MD, Thomas B. Kinney, MD, Michael B. Streiff, MD, Ronald F. Sing, DO, Mary C. Proctor, MS, Daniel Becker, MD, MPH, Mark Cipolle, MD, PhD, Anthony J. Comerota, MD, Steven F. Millward, MD, Frederick B. Rogers, MD, David Sacks, MD, and Anthony C. Venbrux, MD

EDITOR'S NOTE: Endorsed by the American Venous Forum.

J Vasc Interv Radiol 2006; 17:449–459

Abbreviations: DVT = deep vein thrombosis, IVC = inferior vena cava, PE = pulmonary embolism, VTE = venous thromboembolism

RATIONALE FOR THE CONSENSUS CONFERENCE

REMOVABLE vena cava filters for temporary protection from pulmonary embolism (PE) were first proposed in 1967 (1). In 2003 and 2004, the United States Food and Drug Administration approved changes to the instructions for use of three existing permanent filters to allow percutaneous retrieval (2). Filter retrieval was added to the instructions without modification of the indications for placement or the addition of indications for retrieval.

The instructions for use provide physicians with minimal guidance for the use of these devices as removable filters.

Many medical specialties are involved in requesting and placing filters as well as subsequent patient management. The overall use of vena cava filters may be increased by the availability of nonpermanent devices (3). However, there is a paucity of medical literature on these filters (4). On January 14 and 15, 2005, the Society of Interventional Radiology (SIR) convened a multidisciplinary confer-

ence to address the clinical application of nonpermanent vena cava filters. Representatives from interventional radiology, trauma surgery, vascular surgery, and internal medicine participated. The goal of the consensus conference was to develop a document that would provide clinical guidance for all physicians who use these vena cava filters. Specifically, we sought to address the indications for placement of a nonpermanent filter, the management of patients with such a filter in situ, the conditions for discontinuation of caval filtration, the evaluation of patients before discontinuation, and patient management after discontinuation. Filter design, performance, reporting standards, quality assurance, and recommendations for specific device selection were not included in the discussions (5–7).

PURPOSE OF THIS DOCUMENT

The intent of this document is to provide suggestions for the clinical application of nonpermanent vena cava filters. These suggestions can be adapted to conform to local practices. More specifically, the document addresses two types of optional filters available or about to become available

From the Dotter Interventional Institute (J.A.K.), Oregon Health & Science University, Mail Code L-605, 3181 Southwest Sam Jackson Park Road, Portland, Oregon 97239; Department of Radiology (T.B.K.), University of California San Diego Medical Center, San Diego, California; Department of Medicine (M.B.S.), Johns Hopkins University, Baltimore, Maryland; Department of Surgery (R.F.S.), Carolinas Medical Center, Charlotte, North Carolina; Department of Surgery (M.C.P.), University of Michigan Medical Center, Ann Arbor, Michigan; Department of Medicine (D.B.), University of Virginia Health Systems, Charlottesville, Virginia; Department of Surgery (M.C.), Lehigh Valley Hospital, Allentown; Department of Radiology (D.S.), The Reading Hospital, West Reading, Pennsylvania; Jobst Vascular Center (A.J.C.), Toledo, Ohio; Department of Surgery (F.B.R.), University of Vermont, Burlington, Vermont; Department of Radiology (A.C.V.),

George Washington University Medical Center, Washington, DC; and Department of Radiology (S.F.M.), Peterborough Regional Health Center, Omemee, Ontario, Canada. Received December 17, 2005; accepted December 20. Address correspondence to J.A.K.; E-mail: kaufmajo@ohsu.edu

Supported by unrestricted educational grants from anonymous corporate donor, CR Bard, Boston Scientific, Cook Group, Cordis Endovascular, and Terumo.

This article will also appear in the March/April 2006 issue of *Surgery for Obesity and Related Diseases* and the *World Journal of Surgery*.

J.A.K., T.B.K., R.F.S., and F.B.R. have identified a conflict of interest.

© SIR, 2006

DOI: 10.1097/01.RVI.0000203418-39769.0D

Table 1
Key Points of Consensus

1. The primary means of therapy and prophylaxis of VTE are pharmacologic
2. No unique indications for optional vena cava filters exist that are distinct from permanent vena cava filters
3. Some patients with indications for vena cava filters have limited periods of risk of clinically significant PE and/or contraindication to anticoagulation and may not require permanent protection from PE with a vena cava filter
4. Patients with filters in situ should be managed with pharmacologic methods according to their VTE status and risk of anticoagulation as soon as safe and feasible
5. There are no absolute indications for discontinuation of filtration unless the filter itself is a source of documented major morbidity that will be relieved by retrieval or conversion
6. Discontinuation of filtration should only occur when the risk of clinically significant PE is reduced to an acceptable level and is estimated to be less than the risk of leaving the filter in situ
7. The quality of literature on optional vena cava filters is not sufficient to support evidence-based recommendations at this time

in the United States, retrievable and convertible (as described later). The document does not represent an implied, suggested, or legal standard of care.

BASIS OF RECOMMENDATIONS

A standardized approach based on two types of recommendations exists for the generation of guidelines to facilitate clinical treatment decisions for typical patients (8,9). The first is based on the tradeoff between benefits of treatment and risks, harm, and costs. The second is based on the methodologic quality of the underlying evidence. Randomized controlled trials with consistent results provide the basis for the strongest recommendations. Unfortunately, the overwhelming majority of the published data on vena cava filters have come in the form of observational studies (10). Published data were considered insufficient to permit anything more than recommendations based on a consensus of opinions by the writing group. A summary of the major points of consensus is presented in **Table 1**.

INDICATIONS FOR PLACEMENT OF OPTIONAL VENA CAVA FILTERS

Venous Thromboembolism

There are numerous risk factors for venous thromboembolism (VTE), in-

cluding malignancy, thrombophilias, recent major surgery or trauma, increased age, acute major medical illness, previous VTE, and morbid obesity (11–15). Some of these risk factors are transient, such as major surgery and trauma, whereas others are permanent and may even increase in importance over time. Careful evaluation of each patient for the presence of risk and duration of the period at risk for VTE is important when selecting a prevention or treatment strategy.

The primary means of prevention and therapy of VTE is pharmacologic, such as systemic administration of anticoagulant agents (12,16–20). Anticoagulant therapy usually entails an acceptably small risk of bleeding and other complications (20–24). For prevention of VTE, there are additional roles for external mechanical adjuncts including but not limited to lower-extremity sequential compression devices (12,16,18). Thrombolytic therapy of established VTE is useful in patients with severe symptoms or hemodynamic instability (25). Specific protocols for pharmacologic prophylaxis and therapy of VTE are beyond the scope of this document but can be found in numerous published documents (12,16–25).

Role of Vena Cava Filters in Treatment and Prophylaxis of VTE

The sole function of vena cava filters is to prevent clinically significant PE by trapping venous emboli. Vena

cava filters do not prevent or treat venous thrombosis. In general, the use of vena cava filters is indicated when primary therapy cannot be started, must be stopped, or is insufficient to protect patients from clinically significant PE who are at high risk (6,16,17,26,27). When used in patients at risk of developing VTE but who do not yet have it, the purpose of the filter is to prevent clinically significant PE should deep vein thrombosis (DVT) occur. Filters placed for so-called prophylactic indications do not provide prophylaxis for development of DVT.

Permanent Vena Cava Filters

Permanent vena cava filters have been commercially available for more than 35 years. The overall use of permanent vena cava filters has increased dramatically in the United States during the past 20 years (28,29). The exact percentage of patients with objectively confirmed VTE who require vena cava filters is not known, but it is estimated that filters are placed in 3%–11% of cases (3,28,30,31). The use of filters in patients without documented VTE (ie, for prophylactic indications) has increased substantially during the past two decades (28,29).

A large body of clinical experience and published data are available for permanent filters and are summarized in several comprehensive reviews (32–39). Unfortunately, with few exceptions, the literature on permanent filters is comprised of uncontrolled retrospective observational series, case reports, and single-center experiences (10). Although vena cava filters are generally accepted as safe devices, short- and long-term complications may occur (36,39–43). Concerns have been raised regarding the long-term benefits and risks of the use of these devices in some patients (44).

Nonpermanent Caval Filtration Devices

There are currently two types of filters that can provide nonpermanent protection from PE (2,45,46). Optional filters are devices that may remain permanently, whereas temporary filters must be removed as a result of their design constraints. There are two subtypes of optional filters, retrievable and convertible.

Retrievable filters are defined in this document as permanent devices designed for imaging-guided percutaneous removal during device-specific time windows of retrievability with use of catheter-based technologies. These filters can be placed with or without the intent to be retrieved depending on the indications and clinical circumstances. Like all permanent filters, retrievable devices initially affix to the wall of the vena cava by means of hooks, barbs, or radial pressure. Over time, some filter elements become adherent to the wall of the vena cava as a result of endothelial overgrowth (47–53). Filters that are not retrieved function as permanent filters.

Convertible devices are defined in this document as permanent filters that can be altered structurally after implantation to no longer function as filters. These filters can be placed with or without the intent to be converted to a nonfiltration state depending on the indications and clinical circumstances. These devices usually maintain their position in the vena cava with hooks, barbs, or radial pressure. Filter elements are subject to endothelial overgrowth. The filtering capacity of the device can be eliminated during a percutaneous imaging-guided catheter-based procedure. After conversion, some or all of the filter remains in the patient's vena cava but does not provide protection from PE. Filters that are not converted provide permanent filtration.

Temporary filters are defined in this document as devices that are not designed for permanent placement. These are not currently available in the United States. Frequently, these devices do not have hooks, barbs, or any other means for fixation to the wall of the vena cava, but are supported in place by tethers or catheters. The supporting elements frequently traverse long segments of the central venous system, are externalized, and occupy a venous access site. Removal of these devices is required within several weeks before the filter and/or tether becomes adherent to the venous walls (46,54,55). Removal is usually an imaging-guided procedure. Permanent filtration requires removal of the temporary filter and placement of a different device.

Although the general principles in this document can be applied to op-

tional and temporary filters, the focus henceforth will be on optional filters.

The available data on optional devices are even more limited than on permanent filters (4). The few published clinical reports (4,56–61) suggest that optional filters, as a group, are associated with equivalent outcomes to permanent devices. However, there has never been a clinical study to directly compare optional and permanent filters. Percutaneous removal of retrievable filters appears to be a safe procedure with few immediate or late complications (56,57,60,61). Published human data on convertible filters are currently lacking. The benefit of discontinuation of filtration has never been proven, but is inferred from the data available on permanent devices (62). Until more data are available, permanent caval filtration should always be considered when a filter is indicated.

Indications for Optional Filters

Placement of an optional filter with the intent to discontinue filtration through retrieval or conversion should follow the same indications used for permanent vena cava filters. The decision to use an optional filter rather than a permanent filter should be based on the anticipated required duration of protection against clinically significant PE and/or risk of pharmacologic therapy (Fig 1). There are no new unique indications for optional vena cava filters distinct from permanent filters.

In general, indications for all vena cava filters have been divided into absolute, relative, and prophylactic categories (Table 2) (5,6,27,36,39,63). Patients with absolute indications have documented VTE, are at high risk of clinically significant PE, and have a contraindication to or complication or failure of pharmacologic therapy (5,6,17,27,36,39,63). In some patients with contraindications to or complications of anticoagulation, the period during which anticoagulant therapy cannot be used may be temporary or transient (22). Optional vena cava filters can be considered in these situations.

Patients with relative indications for vena cava filters have VTE and are considered to be at continued high risk of clinically significant PE despite pri-

mary therapy, at increased risk of complications of anticoagulation, or noncompliant with medications (Table 2). In general, the data supporting the clinical value of filters for relative indications are more sparse than those for absolute indications. When the period of increased risk for clinically significant PE or complications of anticoagulation is of short duration in patients with relative indications for filters, optional filters may be considered.

Patients with prophylactic indications for filters do not have VTE, but are at increased risk for development of clinically significant PE and unable to undergo primary prophylaxis. Although placement of vena cava filters for these indications is common, the data supporting the practice are weak. The one possible exception is filter placement in a setting of trauma in a patient deemed to be at high risk (64,65). Additional specific clinical scenarios in which the use of prophylactic filters have been reported (but are of unproven benefit) include critically ill patients with a history of VTE and contraindication to anticoagulation (66,67), perioperative settings in patients with a history of VTE and contraindication to anticoagulation (2), and patients undergoing bariatric surgery (68,69). When the period of increased risk for clinically significant PE is of short duration, optional filters may be considered.

MANAGEMENT OF PATIENTS WITH AN OPTIONAL VENA CAVA FILTER IN SITU

Patients with optional vena cava filters require tracking and routine follow-up for several reasons. The window of retrievability varies for each device, patient conditions may change such that discontinuation of the filter is no longer desired or safe, and primary physicians may require guidance on the timing of filter discontinuation. Preferably, the physician who places the filter should perform this follow-up.

Patients with VTE and a vena cava filter should undergo primary therapy at the first safe opportunity regardless of the presence of a vena cava filter (Fig 2). Evidence-based reviews of therapy for VTE are available to guide therapy (16,17,20,71–75). In patients

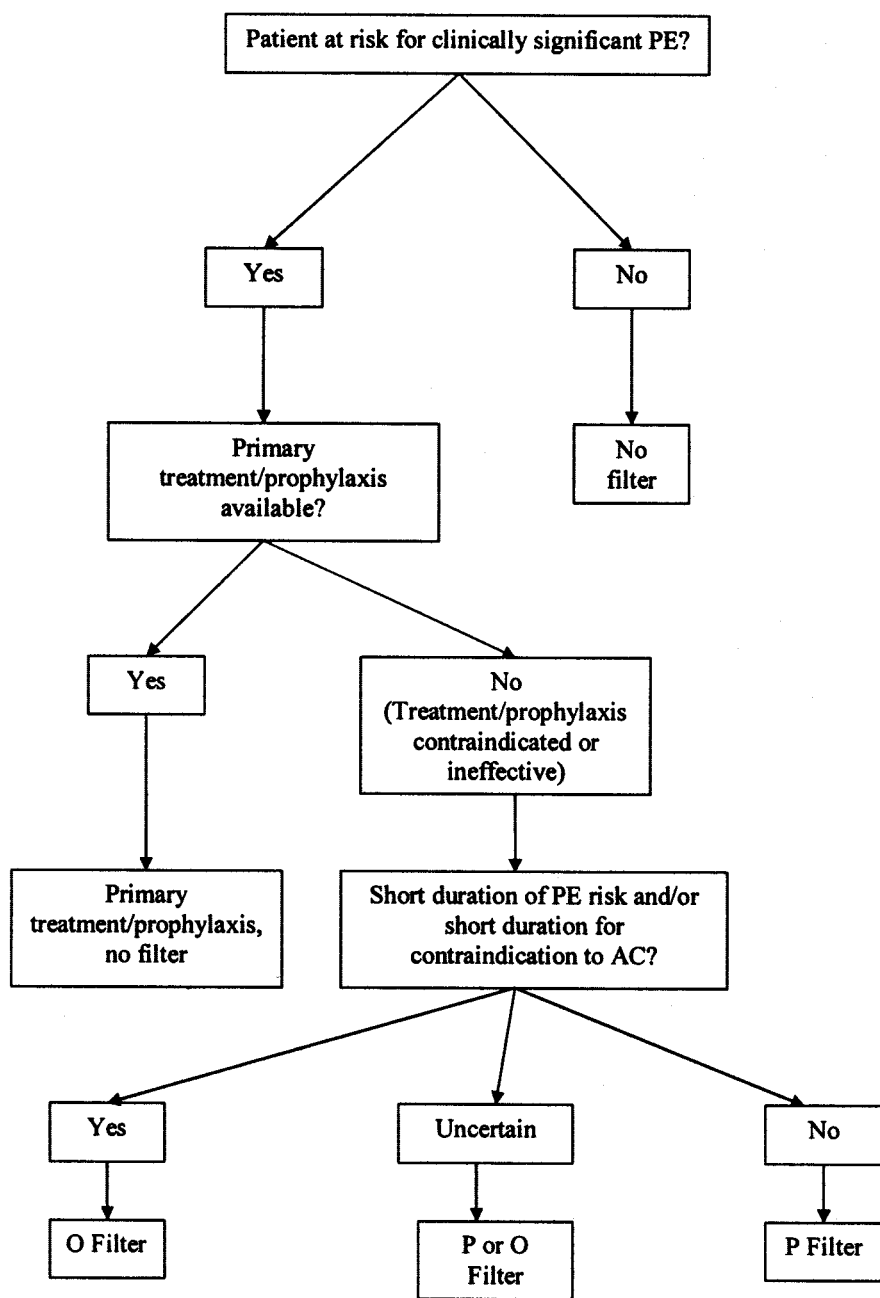


Table 2 Indications and Contraindications for All Vena Cava Filters	
Absolute Indications (Proven VTE)	Recurrent VTE (acute or chronic) despite adequate anticoagulation Contraindication to anticoagulation Complication of anticoagulation Inability to achieve/maintain therapeutic anticoagulation
Relative Indications (Proven VTE)	Iliocaval DVT Large, free-floating proximal DVT Difficulty establishing therapeutic anticoagulation Massive PE treated with thrombolysis/thrombectomy Chronic PE treated with thromboendarterectomy Thrombolysis for ilio caval DVT VTE with limited cardiopulmonary reserve Recurrent PE with filter in place Poor compliance with anticoagulant medications High risk of complication of anticoagulation (eg, ataxia, frequent falls)
Prophylactic Indications (No VTE, primary prophylaxis not feasible*)	Trauma patient with high risk of VTE Surgical procedure in patient at high risk of VTE Medical condition with high risk of VTE
Contraindications to Filter Placement	No access route to the vena cava No location available in vena cava for placement of filter
* Primary prophylaxis not feasible as a result of high bleeding risk, inability to monitor the patient for VTE, etc.	

Figure 1. Algorithm for placement of vena cava filters. PE = Pulmonary embolism; AC = anticoagulation; O = optional vena cava filter (in patients with limited life expectancy [<6 months], there may be limited benefit from retrieval/conversion of a filter [2,45,70]); P = permanent vena cava filter.

with VTE and a vena cava filter placed for a contraindication to anticoagulation, the patient should receive anticoagulation as soon as the period of excess hemorrhagic risk has passed. In the subgroup of patients with VTE whose contraindication to anticoagulation is major surgery, data from randomized clinical trials are lacking, but

several reviews are available to inform clinical decision-making regarding resumption of primary therapy (72,74). For patients with VTE and a vena cava filter placed for a major hemorrhagic complication associated with anticoagulation, the physician may restart anticoagulation when the clinical situation dictates that it is safe. This deci-

sion must be made on a case-by-case basis after the risks and benefits of anticoagulation are weighed. No evidence-based guidelines exist to assist clinical decision-making. However, small case series suggest that anticoagulation may be reinstated when the causal anatomic lesions have been definitively corrected (74,76). Nevertheless, these patients appear to be at higher risk for subsequent episodes of major bleeding (76). Tighter control of anticoagulation management (eg, more frequent International Normalized Ratio determinations) and laboratory surveillance for recurrent hemorrhage are

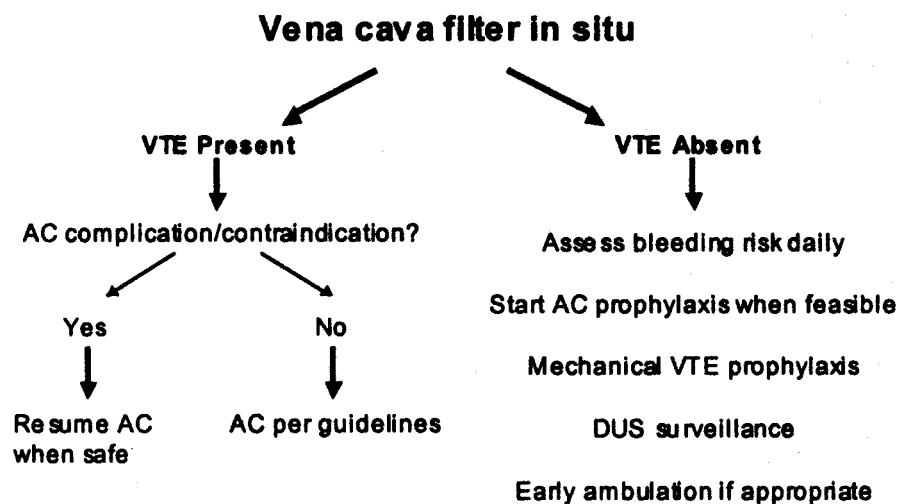


Figure 2. Algorithm for management of patients with filters in situ. AC = anticoagulation; DUS = duplex ultrasound scan.

probably worthwhile additions to routine clinical management.

In patients with filters placed for prophylactic indications, primary VTE prophylaxis should be initiated based on the underlying risk factors at the first safe opportunity regardless of the presence of a vena cava filter. Evidence-based guidelines on VTE prophylaxis are available to guide decision-making (16). Bleeding risk should be formally assessed by the patient care team on a daily basis with the goal to institute appropriate anticoagulant VTE prophylaxis. In addition, mechanical forms of VTE prophylaxis (eg, graduated compression stockings, sequential/pneumatic compression devices) should be used whenever possible. The filter does not provide prophylaxis for venous thrombosis, but rather only for PE should DVT develop. For patients at high risk who are receiving suboptimal VTE prophylaxis, duplex ultrasonographic (US) surveillance for DVT should be considered. In the event that a patient with a filter placed for prophylactic indications develops VTE, appropriate primary therapy should be initiated as soon as is safe.

WHEN TO CONSIDER DISCONTINUATION OF VENA CAVA FILTRATION

General

The sole purpose and function of a vena cava filter is to prevent clinically

significant PE. For this reason, the fundamental clinical criterion for discontinuation of caval filtration is an acceptably low risk of PE (Fig 3). In most instances, this will occur when the patient is receiving satisfactory treatment with primary therapy or has passed the period of risk for VTE (11,14,16,17,34,35,77). When a patient is considered to have an acceptably low risk of PE, the presumed risks of the filter must be weighed against the estimated future risk of recurrent PE. As a result of the inadequacies of published data on filters and the complexity of real clinical situations, the balance of risks cannot be quantified at the present time and remain a matter of physician judgment. The decision to discontinue filtration must be individualized in each case. In the clinical context, the decision to not retrieve or convert a satisfactorily functioning filter is acceptable.

When the local standard of care is to prescribe lifelong anticoagulation simply because of the presence of a vena cava filter, discontinuation of filtration should be considered. Routine anticoagulation of patients with vena cava filters to prevent recurrent DVT and other thrombotic complications is controversial (78,79). Long-term anticoagulation is associated with a small but definable incidence of complications, usually hemorrhagic (22). Discontinuation of filtration to avoid lifelong anticoagulation after the patient

no longer requires treatment of VTE may be warranted.

Recommendations before Discontinuation of Filtration for All Patients

Vena cava filtration may be discontinued in the following clinical scenarios:

1. An indication for a permanent filter is not present. Patients chronically at high risk of clinically significant PE irrespective of management with primary therapy, short life expectancies (≤ 6 months), or noncompliance with primary therapy or follow-up appointments should have a permanent filter. All retrievable and convertible filters can provide permanent protection from PE.

2. The risk of clinically significant PE is acceptably low as a result of achievement of sustained appropriate primary treatment (therapy or prophylaxis) or change in clinical status. Appropriate primary treatment will vary depending on the VTE status of the patient (16,17,19,22,23,65,73,80–82). Patients should demonstrate the ability to tolerate sustained primary treatment before discontinuation of filtration. The period of time required will vary based on the patient's VTE status and local standards of care (as described later).

3. The patient is not anticipated to return to a high-risk state for PE because of interruption of primary treatment, change in clinical management, or change in clinical condition. For example, filtration should not be discontinued when a patient will shortly undergo additional procedures that would normally require placement of a vena cava filter. Although it is not always possible to identify which patients will return to a high-risk status, careful review of all aspects of the patient's care should be conducted before filter retrieval or conversion.

4. The life expectancy of the patient is long enough that the presumed benefits of discontinuation of filtration can be realized. Limited evidence suggests that some suspected complications of filters take years to manifest (42,43). Patients not anticipated to survive more than 6 months are unlikely to derive any discernible benefit from filter retrieval or conversion.

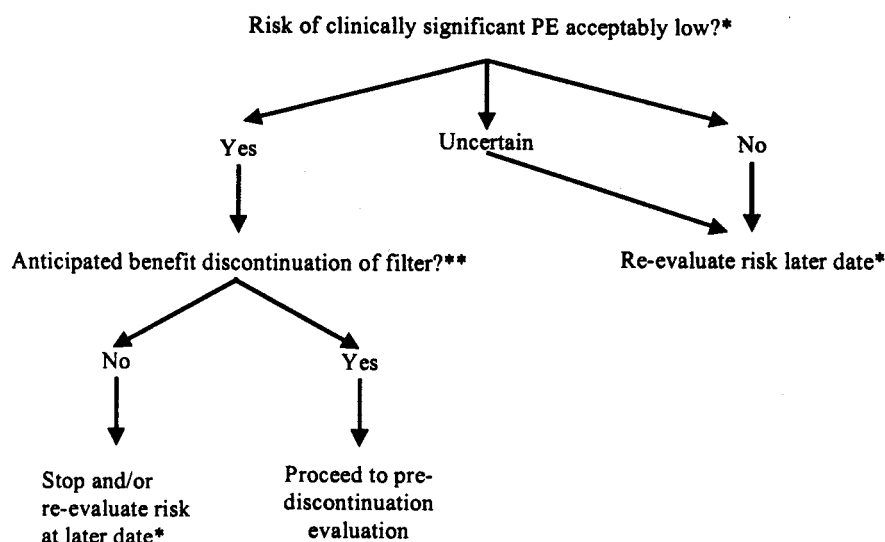


Figure 3. Algorithm for patient selection for discontinuation of vena cava filtration. *Risk of PE determined by patient's current venous thromboembolic disease status, underlying conditions, and tolerance of primary therapy or prophylaxis. **Requires consideration of life expectancy and need for caval filtration in near future.

5. The filter can be safely retrieved or converted. Patients with unmanageable issues related to contrast agents (eg, allergy or renal insufficiency) or coagulopathies should not undergo the procedure until adequate prophylaxis or correction has been performed. Suitable venous access for the procedure should be available. Last, filters that the treating physician judges cannot be safely retrieved or converted without causing unacceptable injury to the vena cava should not be manipulated.

6. The patient or consenting guardian agrees to have the filter removed or converted. Patients who desire to continue caval filtration permanently should be allowed to so.

Specific Recommendations for Patients with VTE

Patients with filters and established VTE should be treated with primary therapy as soon as possible (17). The presence of the filter should not alter the intensity or duration of anticoagulation. The period of highest risk for PE in patients undergoing therapeutic anticoagulation for VTE cannot be precisely defined because of the heterogeneity of published studies. Several studies (42,83,84) suggest that symptomatic PE is most likely to occur within 2–3 weeks of the initial episode of VTE. The duration of highest risk

for clinically significant PE during primary therapy should be estimated individually for each patient. Patients who require laboratory monitoring for anticoagulation should have stable measurements with no evidence of bleeding for at least 7 days before the discontinuation procedure.

Patients with established VTE should not have clinical or objective evidence of failure or a complication of primary therapy before filter retrieval. These situations warrant continued caval filtration, perhaps permanently (39).

Specific Recommendations for Patients without VTE

Patients in whom filters are placed for prophylaxis (ie, those at risk for but without a diagnosis of VTE) should be treated with primary prophylaxis as soon as possible according to published guidelines (16,19,65). Discontinuation of filtration should not occur until adequate primary prophylaxis has been consistently achieved and can be maintained or the high risk of clinically significant PE has abated. In some patients, the period of risk for development of VTE may end before discontinuation of vena cava filtration. At all times, the underlying condition of the patient should determine the need and type of VTE prophylaxis.

When a filter has been placed for

prophylactic indications, there should be no clinical or objective evidence of interval development of VTE before discontinuation of filtration. A patient who develops VTE while a prophylactic filter is in place should be treated with primary therapy for VTE, as outlined earlier (17,73,80). The patient should be at an acceptably low risk of clinically significant PE before discontinuation of filtration is considered.

Unique Situations

When a retrievable filter has become a source of severe morbidity or is no longer protective for PE as a result of change in filter position or loss of structural integrity, removal may be indicated. These cases are very rare, but examples include maldeployment, unmanageable pain related to perforation, filter instability, and dislodgement during other procedures (40,41,85). Conclusive objective evidence of filter-related morbidity should be sought before filter removal for this indication. These occurrences should be reported according to standard device-tracking practices. Placement of another filter may be necessary when retrieval of an in situ device is indicated despite the presence of a continuing indication for a vena cava filter.

PATIENT EVALUATION BEFORE DISCONTINUATION OF FILTRATION

Preprocedural Evaluation

The goals of patient evaluation before filter retrieval or conversion are to ensure that the risk of clinically significant PE is acceptably low and that the retrieval or conversion procedure can be performed safely (Fig 4). A focused history and physical examination should be performed to assess for signs of VTE. Patients suspected of having new, recurrent, or progressive VTE on the basis of symptoms or clinical findings should undergo diagnostic imaging procedures to resolve this question before proceeding. Routine coagulation measurements and complete blood counts are appropriate for the assessment of patients receiving therapeutic anticoagulation. Renal function assessment should be considered in patients at risk for contrast agent nephropathy.

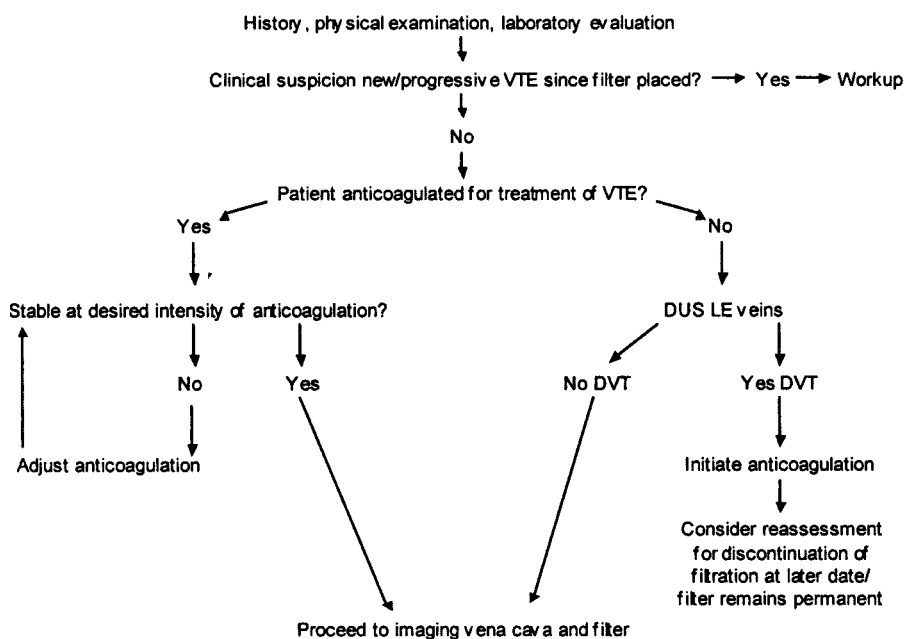


Figure 4. Algorithm for patient evaluation before discontinuation of vena cava filtration.

Patients who have documented VTE should have laboratory values in the appropriate therapeutic range based on laboratory monitoring (17). Laboratory monitoring is not necessary for the majority of patients who are receiving low molecular weight heparins. Patients who have undergone anticoagulation and require laboratory monitoring should have stable measurements with no evidence of bleeding for at least 7 days. In the presence of acute VTE, a delay of 2–3 weeks after initiation of primary therapy should be considered before discontinuation of vena cava filtration (42,83,84). When coagulation studies are warranted for anticoagulation monitoring, they should be performed the day of the discontinuation procedure to ensure that the measurements are within the appropriate therapeutic ranges. It is neither necessary nor desirable to interrupt anticoagulation for the retrieval or conversion procedure.

Patients with VTE who have received full anticoagulation and are in stable condition while receiving primary therapy, and who have no new, recurrent, or progressive symptoms or clinical findings of VTE, do not require additional imaging of the extremity veins or pulmonary arteries before discontinuation of vena cava filtration. If imaging performed for clinical indica-

tions reveals new or progressive VTE, repeat evaluation of the anticoagulation regimen and delay of filter discontinuation should be considered. These patients may be reassessed at a later date for filter retrieval or conversion or the filter may be considered a permanent device.

Patients without a known diagnosis of VTE should undergo imaging of the lower-extremity veins such as duplex venous US before discontinuation of filtration. A finding of DVT in these patients requires postponement of filter discontinuation and initiation of primary therapy if not contraindicated (17). The patient should exhibit standard therapeutic levels of anticoagulation for at least 2–3 weeks before filter discontinuation is reconsidered. Alternatively, the filter may remain in place as a permanent device.

The physician responsible for removing or converting the filter should confirm the appropriateness of discontinuation of filtration before the procedure. During the consent process, the following should be discussed in addition to the usual elements of informed consent: (i) the rationale for discontinuation of filtration, (ii) the possibility that filter retrieval or conversion may not be possible, and (iii) the voluntary nature of discontinuing caval filtration.

Imaging of the Filter and Vena Cava

Imaging of the vena cava and implanted filter can be performed at the time of the discontinuation procedure with catheter-based techniques or within the preceding 24 hours with a technique that permits evaluation of the entire filter and the vena cava such as contrast material-enhanced computed tomography (CT), magnetic resonance venography, or US. In patients with known VTE, identification of thrombus in the filter requires an assessment of the risk of clinically significant PE at the time of filter discontinuation or subsequent to the procedure (Fig 5). There are no published data to support guidelines for making this assessment; an individualized decision by the physician will be required in each case. For example, substantial filling defects within the filter present an immediate risk of PE during filter retrieval or conversion and may indicate an ongoing embolic risk. Conversely, subcentimeter filling defects adherent to filter elements may pose little risk of PE during filter retrieval or conversion and may imply a resolved embolic risk. In some cases, based on the combined judgment of the physicians with primary responsibility for retrieval or conversion of the filter and management of anticoagulation, the patient can return after a period of weeks for repeat imaging and reconsideration of discontinuation of filtration.

In patients without known VTE before the filter retrieval or conversion procedure, identification of trapped thrombus within the filter constitutes a new diagnosis of VTE regardless of the absence of clinical symptoms or normal results of lower-extremity venous US. The filter discontinuation procedure should be terminated and appropriate primary therapy should be instituted unless contraindicated. Reassessment for discontinuation of filtration may be considered at a later time, as described earlier.

MANAGEMENT AFTER DISCONTINUATION OF FILTRATION

During the Procedure

After retrieval or conversion of a filter, imaging of the vena cava may be performed as part of the procedure to

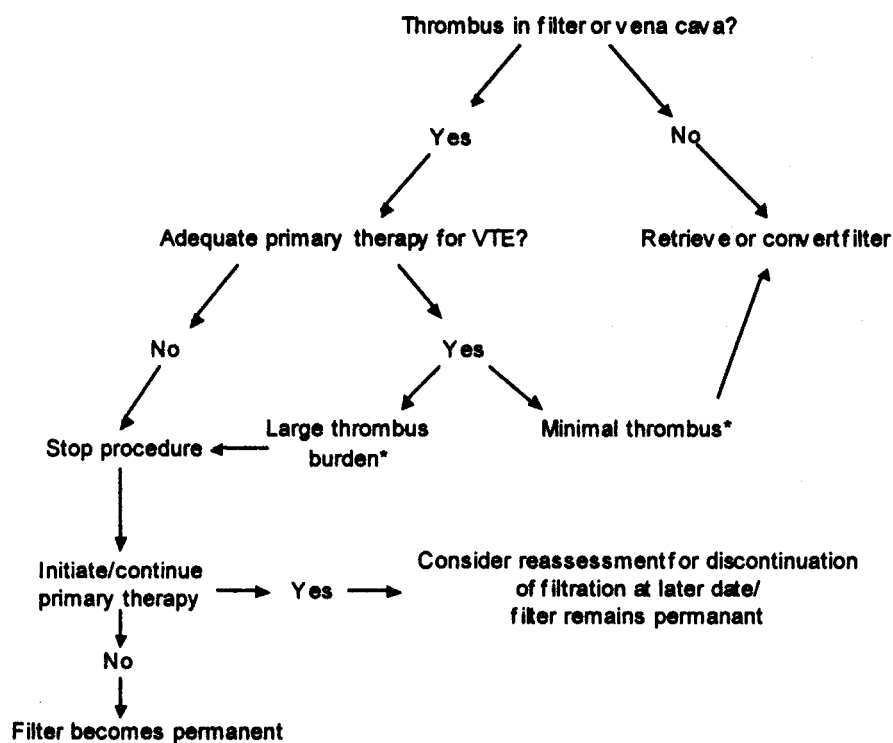


Figure 5. Algorithm for management of thrombus found in a filter before or during a discontinuation procedure. VTE = venous thromboembolism such as deep vein thrombosis or pulmonary embolism. *The determination of the volume and age of thrombus present in a filter is made by the physician performing the retrieval or conversion procedure, as is the clinical significance of the thrombus. Whenever uncertainty prevails about the volume, age, or clinical significance of thrombus in the filter, the filter should remain in place.

assess for evidence of caval trauma or thrombus. Caval imaging is strongly recommended after difficult or prolonged procedures or when a patient reports significant pain during and/or after the procedure. Findings suggestive of caval injury such as intimal flaps or extravasation of contrast medium should be managed according to the degree of the abnormality and local standards of care. There are few data in the published literature to guide management in these cases, although minor abnormalities on caval imaging have been followed expectantly or with anticoagulation without clinical sequelae (86). The presence of obstructive intimal flaps or thrombus may require additional interventions to preserve patency of the vena cava. Patients with suspected retroperitoneal bleeding after discontinuation of filtration may require evaluation with CT, serial hematocrit measurements, and close clinical observation.

Retrieved or converted filters

should be inspected for integrity (directly or with imaging) by the physician performing the procedure. If a filter is incomplete, careful evaluation of the retrieval or conversion catheter and imaging of the patient's abdomen and chest should be performed to localize the missing components and document their position. There are no generally accepted guidelines for the treatment of patients with retained fractured or detached filter elements. Retroperitoneal and intrapulmonary fragments are rarely symptomatic. Intracardiac fragments should be managed in consultation with a cardiac specialist.

After the Procedure

Patients should be treated according to their VTE status and underlying conditions after retrieval or conversion of a filter (16,17,22,65,72–75,80). There are no specific additional therapies required after discontinuation of

vena cava filtration. Patients with VTE should continue to receive primary therapy for the full duration suggested in published practice guidelines or according to local standards of care (17). Patients without VTE should undergo prophylaxis with use of standard techniques appropriate for any underlying conditions (16). All patients should be monitored for new, recurrent, or progressive DVT and/or PE, and if diagnosed, managed accordingly.

FUTURE RESEARCH

Background

For nearly 40 years, vena cava filter research has focused on three areas: in vitro simulations of performance, in vivo tests of function, and patient outcomes. The initial goal of this work was to acquaint physicians with the purpose of these devices and to demonstrate their advantages compared with earlier methods of caval interruption. Over time, this approach became the primary means of evaluating new designs and comparing competitive devices (87).

In vitro studies often compare two or more devices and focus on characteristics such as clot trapping ability, resistance to movement, and flow dynamics. Device manufacturers use proprietary in vitro testing routines to evaluate prototypes and obtain information before the initiation of animal testing. Some tests are validated against an objective standard such as the performance of earlier devices, whereas others rely on face validity (88–92).

In vivo studies of inferior vena cava filters are typically conducted in animal models with an inferior vena cava size similar to that of humans (47, 49,52). The purpose of animal studies is to assess some aspects of device performance in a biologic system. Currently, animal studies are used to test device placement, biocompatibility, stability, impact on caval wall and surrounding structures, thrombus trapping, and removal. Testing in animal models does not evaluate all aspects of performance, especially filter efficacy in a clinical setting, and long-term outcomes.

Human research in filters has been notably devoid of randomized prospective studies. Almost all large

studies are observational in nature and often lack a control group. Determination of outcomes and complications of filters has been based on data that are highly variable in quality, objectivity, and reliability. Although standardized reporting guidelines for studies of filters have been developed, they have not been uniformly adopted by authors or journals (5,7). Significant complications from IVC filters are infrequent. Recognition of these rare events in small observational studies is an unreasonable expectation (57, 93,94). Similarly, large randomized trials before commercialization of new devices are also unreasonable because the number of subjects needed and the cost of the required studies would prevent new devices from coming to the market.

Research Imperatives

General.—The introduction of optional and temporary vena cava filters has created renewed interest in existing questions about filters and raised new questions that need to be investigated. These questions range from the long-term clinical benefits of filters to the clinical outcomes after removal of a filter from the vena cava. Additional levels of testing are necessary at the in vivo, in vitro, and clinical levels for devices that undergo manipulation or removal after initial placement (49,52,89,91,92). **Table 3** lists several basic questions regarding performance of IVC filters.

In vitro testing.—A significant concern with current in vitro testing is the lack of standardization for permanent and optional devices. Research is needed to develop uniformly accepted in vitro tests that accurately predict in vivo function in terms of vena cava flow dynamics, the filter's clot trapping ability, filter stability, filter durability, and the ability to remove or convert the filter. These tests need to be sufficiently robust to allow for differences in filter design characteristics and still be able to reliably measure performance parameters. Computerized modeling and simulations may provide rapid methods to investigate multiple filter designs. Standardized in vitro testing regimens should be developed by representatives from industry, academia, and the Food and Drug Ad-

Table 3
Suggested Research Topics

Validated standardized in vitro tests for filters
Validated standardized animal models for filters
Multiinstitutional clinical registry of filters and/or randomized prospective clinical trials to:
Validate the current relative and prophylactic indications for filters
Compare clinical performance of optional filters with permanent filters
Compare the clinical performance of individual devices
Identify patient populations suitable for short-term caval filtration
Determine criteria for discontinuation of filtration
Determine clinical outcomes of filter removal or conversion
Determine cost effectiveness of discontinuation of filtration

ministration. The tests could then be applied before in vivo evaluation and the results required as part of the approval process for marketing applications.

In vivo testing.—In vivo testing lacks standardization for permanent and optional devices. As suggested for in vitro testing, research is needed to develop a uniformly accepted animal model for testing filters. The extrapolation from animal models to human experience remains inferential. Correlation of hemodynamic, pathologic, and clinical outcomes in animal models with subsequent human clinical experience is necessary. The short- and long-term impact of removable and convertible filters on the vena cava and its environs has been studied only in animals, yet this remains a central concern in the human application of these devices.

Clinical testing.—A national filter registry has been suggested by industry, professional organizations, and academic centers at various times during the past 15 years. Questions regarding the role of temporary, permanent, and optional vena cava filters in prevention of PE need to be addressed. With the use of sound design principles, it is possible to prospectively collect sufficient data to study these issues and to

guide physician practice. Such a registry would provide insight into the use of vena cava filters, an understanding of the types of patients being treated, and the long-term effects of different filter designs. Changes in practice can be observed and studied. Major professional organizations involved with vascular interventional procedures and the treatment of patients with VTE should jointly organize and create such a registry.

Ideally, large randomized prospective studies will ultimately be performed that will address fundamental unanswered questions about filters, such as the validity of the current indications for these devices, impact on mortality from PE after filter placement in specific patient populations, and long-term outcomes. Optional, temporary, and future filter technologies should be studied in the same manner.

New filter materials, devices that can be separated or collapsed, absorbable filters, and drug-eluting filters are currently being studied. The cost of research can be controlled while the pace of advancement increases through programs that integrate in vitro and in vivo studies and use the resulting data to direct clinical development (95). Knowledge of the strengths and liabilities of the present generation of low-profile optional filters can provide the foundation for future filter development.

References

- Williams R, Schenk W. A removable intracaval filter for prevention of pulmonary embolism: early experience with the use of the Eichelher catheter in patients. *Surgery* 1970; 68:999-1008.
- Kaufman J. Retrievable vena cava filters. *Tech Vasc Interv Radiol* 2004; 7:96-104.
- Quirke T, Ritota P, Swan K. Inferior vena caval filter use in U.S. trauma centers: a practitioner survey. *J Trauma* 1997; 43:333-337.
- Stein P, Alnas M, Skaf E, et al. Outcome and complications of retrievable inferior vena cava filters. *Am J Cardiol* 2004; 94:1090-1093.
- Greenfield L, Rutherford R. Recommended reporting standards for vena caval filter placement and patient follow-up. Vena Caval Filter Consensus Conference. *J Vasc Interv Radiol* 1999; 10:1013-1019.
- Grassi C, Swan T, Cardella J, et al. Quality improvement guidelines for percutaneous permanent inferior vena

- cava filter placement for the prevention of pulmonary embolism. SCVIR Standards of Practice Committee. *J Vasc Interv Radiol* 2001; 12:137–141.
7. Millward S, Grassi C, Kinney T, et al. Reporting standards for inferior vena caval filter placement and patient follow-up: supplement for temporary and retrievable/optional filter. *J Vasc Interv Radiol* 2005; 16:441–443.
 8. Guyatt D, Schunemann H, Cook D, et al. Grades of recommendations for antithrombotic agents. *Chest* 2001; 119(suppl 1):S3–S7.
 9. Sackett D. Rules of evidence and clinical recommendations on the use of antithrombotic agents. *Arch Intern Med* 1986; 146:464–465.
 10. Girard P, Stern J, Parent F. Medical literature and vena cava filters: so far so weak. *Chest* 2002; 122:963–967.
 11. Anderson F, Spencer F. Risk factors for venous thromboembolism. *Circulation* 2003; 107:I9–I16.
 12. Haas S. Venous thromboembolic risk and its prevention in hospitalized medical patients. *Semin Thromb Hemost* 2002; 28:577–584.
 13. Hansson P, Sorbo J, Eriksson H. Recurrent venous thromboembolism after deep vein thrombosis: incidence and risk factors. *Arch Intern Med* 2000; 160:769–774.
 14. Heit J. Risk factors for venous thromboembolism. *Clin Chest Med* 2003; 24:1–12.
 15. Kearon C. Epidemiology of venous thromboembolism. *Semin Vasc Med* 2001; 1:7–26.
 16. Geerts W, Pineo G, Heit J, et al. Prevention of venous thromboembolism: the Seventh ACCP Conference on Antithrombotic and Thrombolytic Therapy. *Chest* 2004;126(suppl):338S–400S.
 17. Buller H, Agnelli G, Hull R, et al. Antithrombotic therapy for venous thromboembolic disease: the Seventh ACCP Conference on Antithrombotic and Thrombolytic Therapy. *Chest* 2004;126(suppl):401S–428S.
 18. Gerotziafas G, Samama M. Prophylaxis of venous thromboembolism in medical patients. *Curr Opin Pulm Med* 2004; 10:356–365.
 19. Kearon C. Duration of venous thromboembolism prophylaxis after surgery. *Chest* 2003;124(suppl):386S–392S.
 20. McRae S, Ginsberg J. Initial treatment of venous thromboembolism. *Circulation* 2004; 110:I3–I9.
 21. Warkentin T, Greinacher A. Heparin-induced thrombocytopenia: recognition, treatment, and prevention: the Seventh ACCP Conference on Antithrombotic and Thrombolytic Therapy. *Chest* 2004;126(suppl):311S–337S.
 22. Levine M, Raskob G, Beyth R, et al. Hemorrhagic complications of anticoagulant treatment: the Seventh ACCP Conference on Antithrombotic and Thrombolytic Therapy. *Chest* 2004; 126(suppl):287S–310S.
 23. Kearon C. Long-term management of patients after venous thromboembolism. *Circulation* 2004; 110:I10–I18.
 24. Hirsh J, Bates S. Clinical trials that have influenced the treatment of venous thromboembolism: a historical perspective. *Ann Intern Med* 2001; 134:409–417.
 25. Goldhaber S, Bounameaux H. Thrombolytic therapy in pulmonary embolism. *Semin Vasc Med* 2001; 1:213–220.
 26. Proctor M. Indications for filter placement. *Semin Vasc Surg* 2000; 13:194–198.
 27. Levy J, Duszak R, Akins E, et al. Inferior vena cava filter placement. American College of Radiology. ACR Appropriateness Criteria. *Radiology* 2000;215(suppl):981–997.
 28. Stein P, Kayali F, Olson R. Twenty-one-year trends in the use of inferior vena cava filters. *Arch Intern Med* 2004; 164:1541–1545.
 29. Athanasoulis C, Kaufman J, Halpern E, et al. Inferior vena caval filters: review of a 26-year single-center clinical experience. *Radiology* 2000; 216:54–66.
 30. Anderson F, Wheeler H. Physician practices in the management of venous thromboembolism: a community-wide survey. *J Vasc Surg* 1992; 16:707–714.
 31. Kazmers A, Jacobs L, Perkins A. Pulmonary embolism in Veterans Affairs Medical Centers: is vena cava interruption underutilized? *Am Surg* 1999; 65:1171–1175.
 32. Grassi C. Inferior vena caval filters: analysis of five currently available devices. *AJR* 1991; 156:813–821.
 33. Becker D, Philbrick J, Selby J. Inferior vena cava filters: indications, safety, effectiveness. *Arch Intern Med* 1992; 152:1985–1994.
 34. Velmahos G, Kern J, Chan L, et al. Prevention of venous thromboembolism after injury: an evidence-based report—part I: analysis of risk factors and evaluation of the role of vena caval filters. *J Trauma* 2000;49:132–138.
 35. Velmahos G, Kern J, Chan L, et al. Prevention of venous thromboembolism after injury: an evidence-based report—part II: analysis of risk factors and evaluation of the role of vena caval filters. *J Trauma* 2000; 49:140–144.
 36. Streiff M. Vena caval filters: a comprehensive review. *Blood* 2000; 95:3669–3677.
 37. Girard T, Philbrick J, Angle JF, Becker D. Prophylactic vena cava filters for trauma patients: a systematic review of the literature. *Thromb Res* 2003; 112:261–267.
 38. Kercher K, Sing R. Overview of current inferior vena cava filters. *Am Surg* 2003; 69:643–648.
 39. Kinney T. Update on inferior vena cava filters. *J Vasc Interv Radiol* 2003; 14:425–440.
 40. Ray C, Kaufman J. Complications of inferior vena cava filters. *Abdom Imaging* 1996; 21:368–374.
 41. Savin M, Panicker H, Sadiq S, et al. Placement of vena cava filters: factors affecting technical success and immediate complications. *AJR* 2002; 179:597–602.
 42. 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. Prevention du Risque d'Embolie Pulmonaire par Interruption Cave Study Group. *N Engl J Med* 1998; 338:409–415.
 43. White R, Zhou H, Kim J, et al. A population-based study of the effectiveness of inferior vena cava filter use among patients with venous thromboembolism. *Arch Intern Med* 2000; 160:2033–2041.
 44. Stein P, Hull R, Raskob G. Withholding treatment in patients with acute pulmonary embolism who have a high risk of bleeding and negative serial noninvasive leg tests. *Am J Med* 2000; 109:301–306.
 45. Linsenmaier U, Rieger J, Schenk F, et al. Indications, management, and complications of temporary inferior vena cava filters. *Cardiovasc Intervent Radiol* 1998; 21:464–469.
 46. Millward S. Temporary and retrievable inferior vena cava filters: current status. *J Vasc Interv Radiol* 1998; 9:381–387.
 47. Reekers J, Hoogeveen Y, Wijnands M, et al. Evaluation of the Retrievability of the OptEase IVC Filter in an Animal Model. *J Vasc Interv Radiol* 2004; 15:261–267.
 48. Pavcnik D, Uchida B, Keller F, et al. Retrievable IVC square stent filter: experimental study. *Cardiovasc Intervent Radiol* 1999;22:239–245.
 49. Neuerburg J, Handt S, Beckert K, et al. Percutaneous retrieval of the Tulip vena cava filter: feasibility, short- and long-term changes—an experimental study in dogs. *Cardiovasc Intervent Radiol* 2001; 24:418–423.
 50. Dible A, Musset D, Heissler M, et al. In vivo evaluation of a retrievable vena cava filter—the Dible-Musset filter: experimental results. *Cardiovasc Intervent Radiol* 1998; 21:151–157.
 51. de Gregorio M, Gimeno M, Tobio R, et al. Animal experience in the Gunther Tulip retrievable inferior vena cava filter. *Cardiovasc Intervent Radiol* 2001; 24:413–417.
 52. Brontzos E, Kaufman J, Venbrux A, et al. A new optional vena cava filter: retrieval at 12 weeks in an animal

- model. *J Vasc Interv Radiol* 2003; 14: 763–772.
53. Vesely T, Krysl J, Smith S, et al. Preliminary investigation of the Irie inferior vena caval filter. *J Vasc Interv Radiol* 1996; 7:529–535.
54. Watanabe S, Shimokawa S, Moriyama Y, et al. Clinical experience with temporary vena cava filters. *J Vasc Surg* 2001; 35:285–290.
55. Lorch H, Welger D, Wagner V, et al. Current practice of temporary vena cava filter insertion: a multicenter registry. *J Vasc Interv Radiol* 2000; 11:83–88.
56. Millward S, Oliva V, Bell S, et al. Gunther Tulip retrievable vena cava filter: results from the Registry of the Canadian Interventional Radiology Association. *J Vasc Interv Radiol* 2001; 12:1053–1058.
57. Asch M. Initial experience in humans with a new retrievable inferior vena cava filter. *Radiology* 2002; 225:835–844.
58. Pieri S, Agresti P, Morucci M, et al. Optional vena cava filters: preliminary experience with a new vena cava filter. *Radiol Med (Torino)* 2003; 105:56–62.
59. Hoff W, Hoey B, Wainwright G, et al. Early experience with retrievable inferior vena cava filters in high-risk trauma patients. *J Am Coll Surg* 2004; 199:869–874.
60. Morris C, Rogers F, Najarian K, et al. Current trends in vena caval filtration with the introduction of a retrievable filter at a level I trauma center. *J Trauma* 2004; 57:32–36.
61. Terhaar O, Lyon S, Given M, et al. Extended interval for retrieval of gunther tulip filters. *J Vasc Interv Radiol* 2004; 15:1257–1262.
62. PREPIC. 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; 112:416–422.
63. Jacobs D, Sing R. The role of vena caval filters in the management of venous thromboembolism. *Am Surg* 2003; 69:635–642.
64. Pasquale M, Fabian T. Practice management guidelines for trauma from the Eastern Association for the Surgery of Trauma. *J Trauma* 1998; 44:941–956.
65. Rogers F, Cipolle M, Velmahos G, et al. Practice management guidelines for the prevention of venous thromboembolism in trauma patients: the EAST practice management guidelines work group. *J Trauma* 2002; 53:142–164.
66. Rohrer M, Scheidler M, Wheeler H, et al. Extended indications for placement of an inferior vena cava filter. *J Vasc Surg* 1989; 10:44–50.
67. Legere B, Dweik R, Arrogia A. Venous thromboembolism in the intensive care unit. *Clin Chest Med* 1999; 20:367–384.
68. Sapala J, Wood M, Schuhknecht M, et al. Fatal pulmonary embolism after bariatric operations for morbid obesity: a 24-year retrospective analysis. *Obes Surg* 2003; 13:819–825.
69. Ferrell A, Byrne T, Robison J. Placement of inferior vena cava filters in bariatric surgical patients—possible indications and technical considerations. *Obes Surg* 2004; 14:738–743.
70. Rosen M, Porter D, Kim D. Reassessment of vena cava filter use in patients with cancer. *J Vasc Interv Radiol* 1994; 5:501–506.
71. Lee A. Treatment of venous thromboembolism in cancer patients. *Thromb Res* 2001; 102(suppl):V195–V208.
72. Ansell J, Hirsh J, Poller L, et al. The pharmacology and management of the vitamin K antagonists: the Seventh ACCP Conference on Antithrombotic and Thrombolytic Therapy. *Chest* 2004; 126(suppl):204S–233S.
73. Bates S, Greer I, Hirsh J, et al. Use of antithrombotic agents during pregnancy: the Seventh ACCP Conference on Antithrombotic and Thrombolytic Therapy. *Chest* 2004; 126(suppl):627S–644S.
74. Douketis J. Perioperative anticoagulation management in patients who are receiving oral anticoagulant therapy: a practical guide for clinicians. *Thromb Res* 2003; 108:3–13.
75. Hirsh J, Raschke R. Heparin and low-molecular-weight heparin: the Seventh ACCP Conference on Antithrombotic and Thrombolytic Therapy. *Chest* 2004; 126(suppl):188S–203S.
76. Ananthasubramaniam K, Beattie J, Rosman H, et al. How safely and for how long can warfarin therapy be withheld in prosthetic heart valve patients hospitalized with a major hemorrhage? *Chest* 2001; 119:478–484.
77. Martinelli I. Risk factors in venous thromboembolism. *Thromb Haemost* 2001; 86:395–403.
78. Jones B, Fink J. A prospective comparison of the status of the deep venous system after treatment with intracaval interruption versus anticoagulation. *J Am Coll Surg* 1994; 178:220–222.
79. Ortega M, Gahtan V, Roberts A, et al. Efficacy of anticoagulation post-inferior vena caval filter placement. *Am Surg* 1998; 64:419–423.
80. Monagle P, Chan A, Massicotte P, et al. Antithrombotic therapy in children: the Seventh ACCP Conference on Antithrombotic and Thrombolytic Therapy. *Chest* 2004; 126(suppl):645S–687S.
81. Olin J. Pulmonary embolism. *Rev Cardiovasc Med* 2002; 3(suppl 2):S68–S75.
82. Kearon C. Natural history of venous thromboembolism. *Circulation* 2003; 107:122–130.
83. Carson J, Kelley M, Duff A, et al. The clinical course of pulmonary embolism. *N Engl J Med* 1992; 326:1240–1245.
84. Douketis J, Foster G, Crowther M, et al. Clinical risk factors and timing of recurrent venous thromboembolism during the initial 3 months of anticoagulant therapy. *Arch Intern Med* 2000; 160:3431–3436.
85. Kaufman J, Geller S, Rivitz S, et al. Operator errors during percutaneous placement of vena cava filters. *AJR* 1995; 165:1281–1287.
86. Binkert C, Bansal A, Gates J. Inferior vena cava filter removal after 317-day implantation. *J Vasc Interv Radiol* 2005; 16:395–398.
87. Food and Drug Administration. Guidance for cardiovascular intravascular filter 510(K) submissions. Rockville, MD: FDA, 1999. Available at: www.fda.gov/cdrh/ode/24.pdf.
88. Lorch H, Dallmann A, Zwaan M, et al. Efficacy of permanent and retrievable vena cava filters: experimental studies and evaluation of a new device. *Cardiovasc Intervent Radiol* 2002; 25:193–199.
89. Bruckheimer E, Judelman A, Bruckheimer S, et al. In vitro evaluation of a retrievable low-profile nitinol vena cava filter. *J Vasc Interv Radiol* 2003; 14:469–474.
90. Xian Z, Roy S, Hosaka J, et al. Multiple emboli and filter function: an in vitro comparison of three vena cava filters. *J Vasc Interv Radiol* 1995; 6:887–893.
91. Schroeder T, Elkins R, Greenfield L. Entrapment of sized emboli by the KMA-Greenfield intracaval filter. *Surgery* 1978; 83:435–439.
92. Irie T, Yamauchi T, Makita K, et al. Retrievable IVC filter: preliminary in vitro and in vivo evaluation. *J Vasc Interv Radiol* 1995; 6:449–454.
93. Rousseau H, Perreault P, Otal P, et al. The 6-F nitinol TrapEase inferior vena cava filter: results of a prospective multicenter trial. *J Vasc Interv Radiol* 2001; 12:299–304.
94. Cho K, Greenfield L, Proctor M, et al. Evaluation of a new percutaneous stainless steel Greenfield filter. *J Vasc Interv Radiol* 1997; 8:181–187.
95. Proctor M, Cho K, Greenfield L. Development and evaluation of investigational vena caval filters: the complementary roles of in vitro and in vivo studies. *J Surg Res* 2003; 110:241–254.