Classification System for Inferior Vena Cava (IVC) Appearance Following Percutaneous IVC Filter Retrieval

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Abstract

Objective There is no classification system for describing inferior vena cava (IVC) injuries. The objective of this study was to develop a standardized grading system for venographic appearance of the IVC following percutaneous IVC filter retrieval.

Methods A classification system for the appearance of the IVC on cavograms following percutaneous IVC filter removal was developed consisting of two grading elements; luminal characteristics and extravasation. Luminal narrowing from 0% up to 50% from any cause is grade 1; narrowing between 50 and 99% is grade 2; occlusion is grade 3; and avulsion is grade 4. Absence of extravasation is grade A, contained extravasation is grade B, and free extravasation is grade C. This system was then applied retrospectively to pre- and post-IVC filter retrieval cavograms performed at a single institution from October 2004 through February 2019.

Results 546 retrieval attempts were identified with 509 (93.2%) filters successfully retrieved. 449 cases (88.2%) had both pre-retrieval and post-retrieval imaging appropriate for application of the proposed classification system. Inter-rater reliability was 0.972 for luminal characteristics, 0.967 for extravasation, and 0.969 overall. Consensus grading demonstrated a distribution of 97.3% grade 1, 1.3% grade 2, 1.3% grade 3, and 0.0% grade 4 for post-retrieval luminal characteristics. For extravasation classification, 96.4% of the cases were classified as grade A, 2.7% grade B, and 0.9% grade C.

Conclusion A classification system was developed for describing IVC appearance after IVC filter retrieval, and retrospectively validated using a single center dataset.

Keywords IVC filter • Filter retrieval • Caval extravasation • Caval injury • Grading system

Introduction

Percutaneous removal of retrievable inferior vena cava (IVC) filter is a clinical priority as indwelling filters have been associated with adverse events [1–10]. The US Food and Drug administration (FDA) has issued two safety communications [11, 12] alerting physicians to consider prompt IVC filter removal as soon as protection from pulmonary embolism is no longer needed.

Retrieval of most IVC filters can be performed safely as routine procedures. Advanced techniques have been described for permanent filters [13–15] and retrievable filters that are difficult to engage or remove [13–20]. Complications including high-grade caval stenosis, occlusion, and hemorrhage have been reported, with significant impact on clinical outcomes and healthcare cost.
However, a standardized classification system for describing the appearance of the IVC after percutaneous filter retrieval does not exist. The purposes of the present study are to suggest such a classification system and to retrospectively apply it to a single institutional experience with percutaneous IVC filter retrieval.

**Methods**

All patients who underwent IVC filter retrieval procedures between October 2004 and February 2019 were identified retrospectively using a search engine [23] with institutional review board (IRB) approval. Patients with filters placed at this institution and at outside institutions were included. All filter retrieval procedures were performed in a tertiary hospital.

After obtaining informed consent, filter retrievals were performed percutaneously under moderate sedation, or general anesthesia for indications including airway management difficulties, intolerability of supine positioning, inconsiderable anxiety, or anticipated procedural complexity. Large-diameter occlusion balloons and covered vascular stents were readily available in the event of acute significant caval injury. Access was obtained via the right internal jugular or the common femoral vein, or if necessary, simultaneously. A pre-retrieval posterior-anterior (PA) projection digital subtraction IVC venogram filmed at 4 frames/second with power injection of iodinated contrast (10–20 mL/s for 2 s) or CO₂ (40 mL; in patients with allergy to iodinated contrast or poor renal function) through a 5 French flush catheter positioned inferior to the filter was obtained to evaluate for thrombus or filter associated complications. Additional views were obtained as clinically indicated. If the operator found significant thrombus within the filter, removal would be postponed [24]. Filter retrieval was attempted using a variety of techniques, starting with a simple snare and escalating as necessary. A post-retrieval venogram with the same parameters was then obtained.

Grading of the IVC appearance after filter retrieval was performed by Interventional Radiology (IR) residents (2 junior and 2 senior residents). Discrepancies were adjudicated by an IR attending with 20 years of experience. Only patients with at least one pre- and post-retrieval cavogram in the same projection, performed with iodinated contrast, were evaluated. The cavograms were viewed as pre- and post-retrieval pairs on a standard image viewing workstation. The graders were encouraged to evaluate the image(s) with maximum luminal contrast filling. Grading was performed independently, blind of the relevant clinical characteristics, outcomes, and other graders’ assessment.

Clinical chart review was performed to collect information on age, gender, indication, IVC filter placement date, filter type, filter retrieval date, filter dwell time, filter location (infra renal versus supra renal), preprocedural labs (INR, platelet count), anticoagulation regimen (prior to, during, and after filter retrieval), post-procedural management (additional cross-sectional imaging, transfusion, disposition, and outpatient follow-up), procedure time (based on procedural sedation management records), and fluoroscopy time.

Data were presented as median (interquartile range, or IQR), mean ± standard errors of the mean (SEM), and frequency (percentage) for numerical and categorical variables. Inter-rater reliability was calculated using Cohen’s kappa.

**Definitions**

Routine retrieval techniques referred to the use of a snare and standard sheath without other instruments. Advanced techniques referred to utilization of additional devices or techniques to facilitate filter removal, including sling or snare construction, bronchoscopy forceps, and excimer laser sheath (Spectranetics, Colorado Springs, CO, USA). For routine filter retrievals, patients who were anticoagulated did not interrupt their anticoagulation [25]. Patients undergoing advanced retrievals who were not anticoagulated received therapeutic heparin for the retrieval procedure (loading dose of 70 units/mg/kg; no activated clotting time monitoring given the empiric approach and the lack of established guidelines).

A normal or mildly narrowed (0–50%) IVC based on diameter measurement on cavograms was classified as grade 1, regardless of the underlying cause (spasm, thrombus, or intimal injury). An IVC that was more than 50% narrowed but not occluded was grade 2. An occluded IVC (complete absence of antegrade flow) was grade 3. A presumably avulsed IVC, with visualization of the distracted ends and associated extravasation was grade 4. If characteristics of multiple different grades were present, the highest grade was chosen. Illustrations of the different gradings are shown in Fig. 1, left panel. Venographic examples are shown in Fig. 2.

Absence of extravasation was defined as the lack of contrast beyond the confines of the IVC or its branches (grade A). Contained extravasation (grade B) was defined as contrast outside the walls of the IVC or its branches that remained confined to the immediate vicinity after contrast
had washed out of the IVC, therefore encompassing pseudoaneurysms. Free extravasation (grade C) was defined as continued migration of contrast away from the IVC after contrast had washed out of the IVC. Extravasation was assumed to indicate caval perforation, laceration, or avulsion; distinction among the three was difficult given the limitations of single plane cavograms. Illustrations of the different extravasation gradings are shown in Fig. 1, right panel. Venographic examples are shown in Fig. 3.

Luminal characteristics grade 2 or above and extravasation cases were further reviewed to determine the presence of intimal injury and thrombus. Intimal injury was defined as IVC wall irregularity or visualization of an intimal flap. Thrombus was defined as new intraluminal filling defect not present on the pre-retrieval cavogram.

**Application of the Grading System**

The pre- and post-retrieval cavograms were graded based on the luminal characteristics (grade 1–4) and the degree of extravasation (grade A-C). A combined grade was then assigned. For example, a normal post-retrieval IVC would be designated as 1A. An IVC with > 50% narrowing and contained extravasation would be 2B. An avulsed IVC with free extravasation would be 4C.

**Results**

546 consecutive filter retrieval performed between October 2004 and February 2019 were retrospectively reviewed. Of these, 509 (93.2%) filters were successfully retrieved, 478 (87.5%) on first attempt, and 31 (5.7%) on subsequent attempts. There were 37 (6.8%) unsuccessful retrievals, most of them occurred early during the study period. Three hundred and eighty-nine (71.2%) filters were retrieved with routine techniques and 157 (28.8%) with advanced techniques. Thirty-two (5.9%) cases were performed with general anesthesia. Four (0.7%) cases were performed with CO₂ contrast. Detailed filter retrieval information arranged by filter type is documented in Table 1.

From this cohort there were 449 (88.2%) procedures with pre-retrieval and post-retrieval iodinated contrast cavograms available for IVC grading. Consensus grading on post-retrieval cavograms demonstrated a distribution of 97.3% grade 1, 1.3% grade 2, 1.3% grade 3, and 0.0% grade 4 for luminal characteristics; 96.4% grade A, 2.7% grade B, and 0.9% grade C for extravasations. Inter-rater reliability was 0.972 for luminal characteristics (0.833 if only examining grade 2 and higher) and 0.967 for extravasation (1.000 if only examining grade B and higher). Overall inter-rater reliability was 0.969. The
presumed etiologies for the observed IVC abnormality did not alter application of the grading system. Clinical information of the entire cohort and each individual IVC grading category is shown in Table 2.

The 16 cases of extravasation (3.6%) included eleven 1B, one 3B, three 1C, and one 3C gradings (Table 2). Two (12.5%) cases had pre-existing intimal irregularity on pre-retrieval venography. After IVC filter retrieval, new intimal irregularities were seen in 8 (50.0%) cases, new intimal flap in 1 (6.3%) case, and thrombus in 1 (6.3%) case. Luminal grading was unchanged except for one case (from grade 1A pre-retrieval to grade 3C post-retrieval). Median filter dwell time for the 16 cases was 177.5 days (IQR: 75.5–1106; approximation in one patient was necessary as only the year of the filter placement was obtained). All IVC filters were infra-renal. Pre-, intra-, and post-procedural anticoagulations are shown in Table 2; 7 patients were therapeutic (6 grade B and 1 grade C), 5 patients were sub-therapeutic (4 grade B and 1 grade C), and the rest 4 patients were not on anticoagulation medications; none were supra-therapeutic. Routine retrieval techniques were used in 8 cases, and advanced techniques in the other 8 cases. Cavograms showed contained extravasation (grade B) in 12 cases and free extravasation (grade C) in 4 cases. Eight patients (4 grade B and 4 grade C) underwent intra-procedural watchful waiting, with repeat venogram showing persistent extravasations in 4 patients (1 grade B and 3 grade C initially, all downgraded to grade B) and resolution of extravasation in the other 4 patients. Three procedures (2 grade B and 1 grade C) were terminated before completion.

Fig. 2 Venographic examples corresponding to each luminal grading. Each panel consists of one pre-retrieval venogram image and one post-retrieval venogram image.

a Grade 1 with 0–50% IVC narrowing. b Grade 2 with 50–99% IVC narrowing. c Grade 3 with IVC occlusion. The previously patent central IVC was no longer opacified (arrowheads). Venous collaterals were instead opacified. Adapted with permission per original article’s Creative Commons license (http://creativecommons.org/licenses/by/4.0/) [20]. d Grade 4 with IVC avulsion, typically associated with extravasation (Grade B or C). Free extravasation (Grade C) was visualized in this case. Gross specimen picture showed adherent IVC wall tissue on the retrieved IVC filter. Abdominal computed tomography confirmed IVC wall injury with associated contrast extravasation (arrowheads), retroperitoneal hematoma, and IVC thrombus. Adapted with permission from Saeed et al. [37] article’s original publisher John Wiley and Sons.
based on operator choice. None of the 16 patients required emergent balloon occlusion or covered stent placement. None reported symptoms or exhibited hemodynamic instability during the procedure. All patients remained hemodynamically stable after the procedure and were successfully managed conservatively. Seven patients were admitted for overnight observation (Table 2; 2 grade C patients were admitted to the Intensive Care Unit) with serial hemoglobin and hematocrit monitoring, and discharged home the following day without additional interventions (SIR classification moderate adverse event [26]). The other 9 grade B patients were discharged on the same day following 2-h observation in the post-procedural care unit (SIR classification mild adverse event [26]). One patient with grade B extravasation developed lower extremity swelling and pain at 1-month follow-up, and was found to have IVC occlusion on imaging. Another patient with grade C extravasation had chronic IVC occlusion and associated symptoms. Both patients underwent IVC recanalization eventually. Three other patients (2 grade B and 1 grade C) had self-limited flank/abdominal pain, which did not require additional interventions.

There were 12 cases of grade 2 or above luminal gradings (6 grade 2 and 6 grade 3) (Table 2). Specifically, 8 (66.7%) cases demonstrated similar luminal narrowing before and after filter retrieval, including 5 cases of pre-existing IVC occlusions. The other 4 (33.3%) cases demonstrated progression of luminal narrowing, including 3 cases from grade 1A to grade 2A (discharged the same day; mild adverse event) and 1 case from grade 1A to grade 3C (observed overnight without additional interventions; moderate adverse event). Overall, among the 26 cases of luminal narrowing grade 2 or above and extravasation grade B or above, 15 (57.7%) cases had progression of IVC abnormality from pre- to post-IVC filter retrieval (Table 3).

Fig. 3 Venographic examples corresponding to each extravasation grading. a Grade A with no extravasation. b Grade B with contained extravasation (arrowheads). c Grade C with free extravasation showing continued migration of contrast (arrowheads) beyond the contour of the IVC after intraluminal contrast had washed out of the IVC. Adapted with permission per original article’s Creative Commons license (http://creativecommons.org/licenses/by/4.0/) [20]
Clinically significant IVC injuries associated with filter removal have been reported in the literature [2, 5, 6, 13, 27–29]. Unlike the established grading system for aortic injuries [30, 31], there is no classification system for IVC injuries [32]. The goals of this study were to propose a grading system for IVC injuries after filter retrieval and to report the initial experience of applying the grading system in a single tertiary hospital setting.

A grading system with a luminal component and an extravasation component was devised. The luminal component focused on the degree of stenosis from any cause. The etiologies of the stenosis including spasm, thrombus, intimal flap, and dissection were not determined due to the limitations of single plane cavograms, commonly mixed causes of stenosis, and the lack of consensus on management strategies. The goal was to standardize reporting, with the assumption that the degree of luminal compromise after filter removal has a major impact on management.

The degree of extravasation was reflective of the IVC wall integrity after filter removal. Although it would be ideal to assess the extent of the injury and quantify the rate of extravasation, the limitations of single plane cavograms precluded assessment beyond absence, contained, or free extravasation. The goal was to standardize reporting on the degree of extravasation as it may lead to additional interventions or otherwise alter management.

Overall inter-rater reliability was optimal. For luminal characteristics, the biggest initial discrepancy was between normal and mild narrowing (not reported). Even objective measurements on the cavograms could not resolve the discrepancy due to small variations in caliber placements. Although for investigative purposes it may be useful to distinguish between normal and mild narrowing, it is not clinically relevant as flow is unimpeded. When grade 1 encompassed both normal and mild intra-luminal narrowing, the inter-rater reliability was excellent at 0.972.

Extravasation was encountered with both routine and complex retrieval techniques. The extravasations seen with routine technique were more likely contained, while those encountered with complex techniques were more likely to be free extravasation. Advanced techniques are more aggressive, require more time, and have known increased complication rates [20, 33, 34]. Given the small number of extravasations, potential associations between free extravasations and specific retrieval instrument, technique, filter type, or other factors were not assessed. Inter-rater reliability was optimal at 0.972 for extravasation grading.

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In this series, 2.7% cases had luminal narrowing of more than 50% (grade 2 and 3) and 3.6% cases demonstrated extravasations (grade B and C). There numbers were

| Filter type     | Count #1 | Successful initial retrieval (% of count #1) | Complex retrieval (% of count #1) | Unsuccessful initial retrieval (Count #2) | Successful subsequent retrieval (% of count #2) | Filters never retrieved |
|-----------------|----------|---------------------------------------------|-----------------------------------|------------------------------------------|-----------------------------------------------|------------------------|
| Gunther-Tulip (Cook) | 392      | 351 (89.5%)                                | 42 (10.7%)                        | 41                                       | 21 (51.2%)                                    | 20                     |
| Celect (Cook)    | 42       | 35 (83.3%)                                 | 18 (42.9%)                        | 7                                        | 2 (28.6%)                                     | 5                      |
| Option (Rex Medical) | 31       | 27 (87.1%)                                 | 11 (35.5%)                        | 4                                        | 1 (25.0%)                                     | 3                      |
| OptEase (Cordis)| 20       | 14 (70.0%)                                 | 4 (20.0%)                         | 6                                        | 2 (33.3%)                                     | 4                      |
| ALN (ALN)       | 13       | 11 (84.6%)                                 | 1 (7.7%)                          | 2                                        | 1 (50.0%)                                     | 1                      |
| G2 (Bard)       | 11       | 10 (90.9%)                                 | 3 (27.3%)                         | 1                                        | 0 (0.0%)                                      | 1                      |
| Recovery (Bard) | 10       | 9 (90.0%)                                  | 1 (10.0%)                         | 1                                        | 1 (100.0%)                                    | 0                      |
| Denali (Bard)   | 8        | 7 (87.5%)                                  | 4 (50.0%)                         | 1                                        | 0 (0.0%)                                      | 1                      |
| G2 Express (Bard) | 7        | 6 (85.7%)                                  | 2 (28.6%)                         | 1                                        | 1 (100.0%)                                    | 0                      |
| Meridian (Bard) | 7        | 5 (71.4%)                                  | 1 (14.3%)                         | 2                                        | 1 (50.0%)                                     | 1                      |
| TrapEase (Cordis)* | 3      | 1 (33.3%)                                  | 1 (33.3%)                         | 2                                        | 1 (50.0%)                                     | 1                      |
| Greenfield (Boston Scientific) * | 2 | 2 (100.0%) | 2 (100.0%) | 0 | 0 | 0 |
| Total           | 546      | 478                                         | 90                                | 68                                       | 31                                            | 37                     |

* denotes permanent type IVC filters

Table 1 IVC filter removals between October 2004 and January 2019, arranged by filter type

Discussion

Clinically significant IVC injuries associated with filter removal have been reported in the literature [2, 5, 6, 13, 27–29]. Unlike the established grading system for aortic injuries [30, 31], there is no classification system for IVC injuries [32]. The goals of this study were to propose a grading system for IVC injuries after filter retrieval and to report the initial experience of applying the grading system in a single tertiary hospital setting.

A grading system with a luminal component and an extravasation component was devised. The luminal component focused on the degree of stenosis from any cause. The etiologies of the stenosis including spasm, thrombus, intimal flap, and dissection were not determined due to the limitations of single plane cavograms, commonly mixed causes of stenosis, and the lack of consensus on management strategies. The goal was to standardize reporting, with the assumption that the degree of luminal compromise after filter removal has a major impact on management.

The degree of extravasation was reflective of the IVC wall integrity after filter removal. Although it would be ideal to assess the extent of the injury and quantify the rate of extravasation, the limitations of single plane cavograms precluded assessment beyond absence, contained, or free extravasation. The goal was to standardize reporting on the degree of extravasation as it may lead to additional interventions or otherwise alter management.

Overall inter-rater reliability was optimal. For luminal characteristics, the biggest initial discrepancy was between normal and mild narrowing (not reported). Even objective measurements on the cavograms could not resolve the discrepancy due to small variations in caliber placements. Although for investigative purposes it may be useful to distinguish between normal and mild narrowing, it is not clinically relevant as flow is unimpeded. When grade 1 encompassed both normal and mild intra-luminal narrowing, the inter-rater reliability was excellent at 0.972.

Extravasation was encountered with both routine and complex retrieval techniques. The extravasations seen with routine technique were more likely contained, while those encountered with complex techniques were more likely to be free extravasation. Advanced techniques are more aggressive, require more time, and have known increased complication rates [20, 33, 34]. Given the small number of extravasations, potential associations between free extravasations and specific retrieval instrument, technique, filter type, or other factors were not assessed. Inter-rater reliability was optimal at 0.972 for extravasation grading.

In this series, 2.7% cases had luminal narrowing of more than 50% (grade 2 and 3) and 3.6% cases demonstrated extravasations (grade B and C). There numbers were
Table 2  Patient characteristics of the entire patient cohort \((n = 449)\)

| Clinical Variable                                      | Luminal characteristics | Extravasation |
|--------------------------------------------------------|-------------------------|---------------|
|                                                        | Grade 1 \((n = 437)\)   | Grade 2 \((n = 6)\) | Grade 3 \((n = 6)\) | Grade A \((n = 433)\) | Grade B \((n = 12)\) | Grade C \((n = 4)\) |
| Age (years; mean ± SEM)                                 | 53.3 ± 0.8              | 59.2 ± 10.3    | 61.0 ± 5.4   | 53.7 ± 0.8              | 47.3 ± 4.4              | 51.3 ± 7.2               |
| Gender (female)                                         | 193 (44.2%)             | 6 (100.0%)     | 2 (33.3%)    | 191 (44.1%)             | 8 (66.7%)               | 2 (50.0%)                 |
| Dwelling time (days; median, IQR)                       | 84.5 (41.3–192)         | 180 (29.8–1567)| 872.5 (240.8–3559)| 85 (40.3–192)         | 142.5 (75.5–345)        | 4768 (1111–8000)          |
| Procedure duration (mins; mean ± SEM)                   | 69.9 ± 2.9              | 85.0 ± 27.2    | 138.7 ± 22.3 | 71.1 ± 2.9              | 52.7 ± 16.1             | 112.3 ± 25.0             |
| Fluoroscopy time (mins, mean ± SEM)                     | 11.3 ± 0.7              | 12.1 ± 3.0     | 53.6 ± 8.4   | 37.8 ± 0.7              | 20.2 ± 7.8              | 37.8 ± 14.7              |
| Infrarenal location                                    | 419 (95.9%)             | 6 (100.0%)     | 6 (100.0%)   | 415 (95.8%)             | 12 (100.0%)             | 4 (100.0%)               |
| Indication                                             |                         |               |             |                         |                         |                           |
| DVT                                                    | 232 (53.1%)             | 4 (66.7%)      | 2 (33.3%)    | 230 (53.1%)             | 5 (41.7%)               | 3 (75.0%)                 |
| PE                                                     | 164 (37.5%)             | 2 (33.3%)      | 4 (66.7%)    | 163 (37.6%)             | 7 (58.3%)               | 1 (25.0%)                 |
| Other                                                  | 41 (9.4%)               | 2 (100.0%)     | 6 (100.0%)   | 40 (9.2%)               |                         |                           |
| Filter type                                            |                         |               |             |                         |                         |                           |
| Gunther-Tulip (Cook)                                   | 319                     | 2             | 2           | 314                     | 8                       | 1                          |
| Celect (Cook)                                          | 34                      | 1             | 1           | 33                      | 3                       |                            |
| Option (Rex Medical)                                   | 24                      | 1             |             | 24                      | 1                       |                            |
| OptEase (Cordis)                                       | 15                      | 1             |             | 15                      |                         |                            |
| ALN (ALN)                                              | 11                      | 1             |             | 11                      |                         |                            |
| G2 (Bard)                                              | 8                       | 1             |             | 9                       |                         |                            |
| Recovery (Bard)                                        | 9                       |               |             | 9                       |                         |                            |
| Denali (Bard)                                          | 6                       | 1             |             | 7                       |                         |                            |
| G2 Express (Bard)                                      | 5                       |               |             | 5                       |                         |                            |
| Meridian (Bard)                                        | 4                       | 1             |             | 5                       |                         |                            |
| TrapEase (Cordis)                                      | 1                       | 1             | 1           | 1                       |                         |                            |
| Greenfield (Boston Scientific)                         | 2                       |               |             | 2                       |                         |                            |
| Pre-procedural labs                                    |                         |               |             |                         |                         |                           |
| INR (mean ± SEM)                                       | 1.64 ± 0.04             | 1.45 ± 0.07    | 1.46 ± 0.25  | 1.64 ± 0.04             | 1.62 ± 0.16             | 1.25 ± 0.25               |
| Platelet count (mean ± SEM)                            | 283 ± 7                 | 217 ± 27      | 232 ± 22    | 283 ± 7                 | 267 ± 24                | 231 ± 26                  |
| Pre-procedural anticoagulation                         |                         |               |             |                         |                         |                           |
| Warfarin                                               | 153                     | 1             | 3           | 152                     | 5                       |                            |
| Warfarin bridged with Lovenox                          | 23                      | 1             | 1           | 21                      | 2                       | 2                          |
| Heparin                                                | 7                       | 2             |             | 9                       |                         |                            |
| Lovenox or other -parin therapeutic dosing (not as bridging) | 73                    | 1             |             | 72                      | 2                       |                            |
| Lovenox prophylactic dosing                           | 30                      |               |             | 30                      |                         |                            |
| Xa inhibitor (-xaban)                                  | 74                      | 1             | 2           | 76                      | 1                       |                            |
| Xa substitute (-parinux)                               | 5                       |               |             | 5                       |                         |                            |
| Thrombin inhibitor (argatroban, dabigatran, lepirudin, etc.) | 2                     |               |             | 2                       |                         |                            |
| None                                                   | 70                      | 66            | 2           | 2                       | 2                       |                            |
| Anticoagulation discontinued prior to IVC filter retrieval | 31 (7.1%)             | 0 (0.0%)      | 1 (16.7%)   | 30 (6.9%)               | 2 (16.7%)               | 0 (0.0%)                  |
Table 2 continued

| Clinical Variable | Luminal characteristics | Extravasation |
|-------------------|-------------------------|---------------|
|                   | Grade 1 \((n = 437)\) | Grade 2 \((n = 6)\) | Grade 3 \((n = 6)\) | Grade A \((n = 433)\) | Grade B \((n = 12)\) | Grade C \((n = 4)\) |
| Intra-procedural anticoagulation | | | | | | |
| Heparin | 56 (12.8%) | 4 (66.7%) | 4 (66.7%) | 59 (13.6%) | 2 (116.7%) | 3 (75.0%; 1 reversed with protamine sulfate) |
| None | 381 (87.2%) | 2 (33.3%) | 2 (33.3%) | 374 (86.4%) | 10 (83.3%) | 1 (25.0%) |
| Post-procedural anticoagulation | | | | | | |
| Warfarin | 170 | 1 | 3 | 167 | 6 | 2 |
| Heparin | 3 | 1 | 4 | | | |
| Lovenox or other -parin therapeutic dosing | 65 | 2 | 1 | 68 | 1 | |
| Lovenox prophylactic dosing | 28 | | | 28 | | |
| Xa inhibitor (-xaban) | 83 | 2 | 2 | 85 | | 1 |
| Xa substitute (-parinux) | 4 | | | 4 | | |
| Thrombin inhibitor (argatroban, dabigatran, lepirudin, etc.) | 3 | | | 3 | | |
| None | 81 | | | 74 | 4 | 2 |
| Filter retrieved? | | | | | | |
| Complex retrieval technique | 427 (97.7%) | 4 (66.7%) | 5 (83.3%) | 423 (97.7%) | 10 (83.3%) | 3 (75.0%) |
| Additional cross-sectional imaging | 82 (18.8%) | 1 (16.7%) | 4 (66.7%) | 83 (19.2%) | 2 (16.7%) | 2 (50.0%) |
| Post-procedural transfusion | 10 (2.3%) | 0 (0.0%) | 1 (16.7%) | 7 (1.6%) | 4 (33.3%) | 0 (0.0%) |
| Post-procedural disposition | | | | | | |
| Discharge | 358 | 4 | 1 | 354 | 9 | |
| Overnight observation | 5 (3 unplanned) | 4 (3 unplanned) | 5 (2 unplanned) | 1 (1 unplanned) | 3 (3 unplanned) | |
| Admission | 74 (6 unplanned) | 2 (0 unplanned) | 1 (0 unplanned) | 74 (4 unplanned) | 2 (2 unplanned) | 1 (0 unplanned) |
| Outpatient follow-up specifically for IVC injury | 15 (3.4%) | 0 (0.0%) | 4 (66.7%) | 15 (3.5%) | 3 (25.0%) | 1 (25.0%) |

Table 3 Pre-retrieval and post-retrieval IVC characteristics for the 12 cases with luminal grading 2 and above after IVC filter removal

| Post-retrieval | Pre-retrieval |
|----------------|---------------|
| Grade | Intimal injury | Thrombus | Grade | Intimal Injury | Thrombus |
| 2A | No | No | 1A | No | No |
| 2A | No | No | 1A | No | No |
| 2A | No | Yes | 2A | Yes | No |
| 2A | Yes | Yes | 1A | No | No |
| 2A | Yes | Yes | 2A | No | Yes |
| 3A | N/A | No | 3A | No | No |
| 3A | N/A | No | 3A | No | No |
| 3B | N/A | No | 3A | No | No |
| 3C | N/A | Yes | 1A | No | Yes |
| 3A | N/A | Yes | 3A | No | Yes |
| 3A | N/A | Yes | 3A | No | Yes |
similar to the rate of moderate or substantial caval stenosis [2, 35, 36] and extravasation [36] reported previously. Among these cases, 57.7% had different grading from pre-to post-IVC filter retrieval, or 2.5% overall.

Limitations of this study not already discussed included absence of clinical examples for all grades of caval stenosis in the dataset, retrospective application in a single center experience, readers of various expertise, and absence of pathological and cross-sectional imaging confirmation. Despite the size of the collected clinical database, the low incidence of high-grade IVC injuries or extravasations prevented statistical correlations with different clinical outcomes. In addition, this grading system does not address the highly variable management of IVC abnormalities after percutaneous filter retrieval. However, with high inter-rater agreement and compatibility with different imaging modalities, the proposed classification system may serve as a foundation for better communication, clinical management development and standardization, and future research. Further validation and modification of the grading system would best occur in a multi-institutional setting, such as a prospective filter retrieval registry.

Conclusion

A grading system for standardized descriptions of IVC appearance after percutaneous filter removal was developed and validated at a single tertiary hospital. This grading system can be used as a framework for better communication between physicians, future research on IVC injuries, clinical management standardization, and patient outcome prognostication.

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Declarations

Conflict of interest Ningcheng Li, Roberto Galuppo, Maxwell Cretcher, Dennis Barbon, Cameron Loudill, Dominik Prosser, Greg Rufener, McKinna Tiliotson, Joseph O’Sullivan, Younes Jahangiri, have nothing to disclose. Ramsey Al-Hakim reports grants from SIR Foundation, during the conduct of the study; other from Auxetics, Inc., personal fees from Penumbra, outside the submitted work; In addition, Dr. Al-Hakim has a patent auxetic stents for managing venous stenosis pending. Khashayar Farsad reports other from Auxetics, Inc, personal fees from Cook Medical, personal fees from BTG, personal fees from Neuwave, grants and personal fees from Guerbet, LLC, personal fees from Genentech, personal fees from Dova Pharmaceuticals, personal fees from Eisai, personal fees from Inquis Medical, Inc, grants from W.L. Gore, outside the submitted work; In addition, Dr. Farsad has a patent “use of specific stent class for the management of venous stenosis” pending. John A. Kaufman reports grants from NIH, personal fees from VIVA Physicians, other from Elsevier, other from HATCH Medical, other from Vu Medi, other from Endoshape, personal fees from Cook Medical, other from Auxetics, personal fees from Argon, other from Modyx.ai, outside the submitted work; In addition, Dr. Kaufman has a patent auxetic stents for managing venous stenosis pending.

Consent for Publication For this type of study consent for publication is not required.

Ethical Approval For this type of study formal consent is not required.

Informed Consent This study has obtained IRB approval from OHSU and the need for informed consent was waived.

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