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VASCULAR-INTERVENTIONAL

Cavographic vs. cross-sectional measurement of the inferior vena cava diameter before filter placement: are we routinely oversizing?

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Abstract

Objective A megacava (vena cava with a diameter of 28 mm or greater) requires a particular filter to avoid migration. However, caval morphologies are variable. As the inferior vena cava (IVC) usually adopts a circular geometry after a filter is inserted, this study aims (a) to classify caval geometry and orientation; (b) to compare discrepancy between anterioposterior projective diameter (PD) and circumference-based calculated diameter (CD) measurements on cross-sectional computed tomography (CT) images; (c) if a discrepancy exists, determine how often it can affect IVC filter selection.

Methods A total of 1503 patients were retrospectively reviewed. Caval morphology was classified. PD and CD were measured at infrarenal IVC. Differences between the PD and CD were assessed by the Wilcoxon signed-rank test or paired *t* test (if appropriate). The scatterplot of PD vs. CD was used to show whether one is consistently larger than the other.

Results The PD was significantly larger than the CD (22.3 ± 3.5 vs. 20.4 ± 2.8, $p < 0.001$). The caval morphologies were divided into five types. Type 1 was oval IVC oriented left-anterior-oblique to the horizontal line with an angle ($n = 999$, 66.5%), type 2 was round IVC ($n = 49$, 3.3%), type 3 was oval IVC with a vertical long axis ($n = 8$, 0.5%), type 4 was oval IVC with a horizontal long axis ($n = 75$, 5.0%), and type 5 was irregularly shaped IVC ($n = 372$, 24.7%).

Conclusion Patients with round IVC are rare. Measurement of CD may be better to assess maximum IVC diameter compared with PD for the purpose of IVC filter placement.

Key Points

- *Five types of IVC orientation are described in this paper: type 1 (n = 999, 66.5%), type 2 (n = 49, 3.3%), type 3 (n = 8, 0.5%), type 4 (n = 75, 5.0%), and type 5 (n = 372, 24.7%).*
- *The incidence of megacava (vena cava with a diameter of 28 mm or greater) measured on anterioposterior projective imaging may be overestimated.*
- *As an IVC will adopt a circular geometry following filter placement, circumference-based calculated diameter may be an appropriate approach for caval size determination.*

Keywords Tomography, X-ray computed · Vena cava, inferior · Sample size

Abbreviations

CD	Calculated diameter
CT	Computed tomography
CCC	Concordance correlation coefficient
IVC	Inferior vena cava
PD	Projective diameter
PE	Pulmonary embolism

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Introduction

Inferior vena cava (IVC) filters have been widely used to prevent acute pulmonary embolism (PE) for more than three decades. Since the first IVC filter was introduced in the late 1960s, more than 259,000 IVC filters have been placed in the USA alone by 2012 [1]. However, filter-related complications, such as migration or perforation, are not uncommon [2], especially in patients with megacava (a caval diameter of 28 mm or greater). Filter migration is related to underestimation the size of IVC, and perforation is associated with overestimation [3, 4]. Thus, it is crucial to measure the true size of the IVC before filter placement.

Conventional cavogram is a two-dimensional image that has been widely used as the standard for measuring caval diameter [5–8]. However, since the IVC always shows variable and frequently oblique orientation, measuring the diameter based on this two-dimensional image may not be accurate [9]. The geometry and orientation of the IVC are altered by filter placement, and cross-sectional computed tomography (CT) imaging can provide information on anticipated vessel diameter when the circumference changes from an oblique orientation to a circular geometry [3, 10]. Therefore, our study aims to (a) classify the geometry of the IVC on cross-sectional CT imaging; (b) assess for a discrepancy between the anterioposterior projective diameter (PD) on cross-sectional CT imaging and the circumference-based calculated diameter (CD); (c) if a difference between PD and CD existed, determine how often IVC filter selection will be affected, in other words, determine how often one method calculates an IVC diameter of 28 mm or less while the other method calculates a diameter greater than 28 mm.

Materials and methods

Study population

This retrospective study was approved by the institutional review board in accordance with the approved guidelines from our hospital and was compliant with HIPAA. Written informed consent was obtained from all patients.

A search of Picture Archiving and Communication Systems between October 2015 and April 2016 was performed, and a total of 1619 patients who underwent abdominal contrast-enhanced CT were included. After reviewing the patients' medical records, 116 patients were excluded. Exclusion criteria were as follows: (a) known caval hemodynamic changes such as occlusion of the IVC ($n = 20$), right heart failure ($n = 12$), pericardial tamponade ($n = 6$), and constrictive pericarditis ($n = 3$); (b) hypovolemic diseases, such as massive ascites ($n = 36$), and hemorrhagic shock ($n = 8$); (c) IVC variations such as duplication of IVC ($n = 8$) and left-sided IVC ($n = 5$); (d) pediatric patients ($n = 18$). Finally, the study population consisted of 1503 patients (890 males and 613 females, ranging in age from 18 to 89 years with a mean age of 52.4 ± 13.7 years). A flowchart of the study population is shown in Fig. 1.

Imaging protocol

All CT examinations were performed on a single machine (SOMATOM Force, Siemens Healthineers), and images were acquired during a single inspiratory breath hold. The acquisition protocol was spiral mode, supine position, with 0.6-s slices, 0.5-s rotation time, collimation 4 to 64 by 1.25 mm, 0.5 to 5 mm of reconstructed slice thickness. Contrast agent (Omnipaque, GE Healthcare) was administered through an 18-gauge cubital intravenous access.

Imaging analysis

Two radiologists with 12 years and 23 years of abdominal image experience, who were blinded to the clinical data reviewed all CT images. The classification of IVC on cross-sectional CT imaging was divided into five types based on the geometry and orientation. The PD on a simulated anterioposterior projection of the IVC was measured as that which would be equivalent to the standard anterioposterior view under cavography, and the circumference of the IVC was measured by manual contouring on cross-sectional CT (Fig. 2). Both PD and circumference were measured on infrarenal IVC at the level of 4 cm below the lowest renal vein, corresponding to the most common location for IVC filter placement. During measurement, the window width and level in each patient were kept consistent between the two reviewers. The PD and circumference measures between two radiologists were averaged for each patient. The CD of the IVC was calculated using the following equation: CD = circumference/π.

According to the IVC classification, the caval morphologies were divided into five types. Type 1 is an oval IVC oriented left-anterior to right-posterior oblique orientation to the horizontal line with an angle (Fig. 3a). Type 2 is a round IVC (Fig. 3b). Type 3 is an oval IVC with a vertical long axis (Fig. 3c). Type 4 is an oval IVC with a horizontal long axis (Fig. 3d). Type 5 is an irregularly shaped IVC (Fig. 3e).

Statistical analysis

Statistical analysis was performed using commercially available software (SAS 9.4, SAS Institute Inc.). Continuous variables were described as mean ± standard deviation (SD). Differences between PD and CD in the overall study population and within each subgroup were assessed with the Wilcoxon signed-rank test or paired t test (if appropriate). The scatterplot of PD vs. CD was used to show whether one is consistently larger than the other in the entire study population and within each subgroup. The Lin concordance correlation coefficient (CCC) was performed to evaluate the interrater agreement between two reviewers. Agreement was classified as poor (CCC, 0–0.40), fair to good (CCC, 0.40–0.75), or excellent (CCC, > 0.75). A p value less than 0.05 was considered statistically significant.

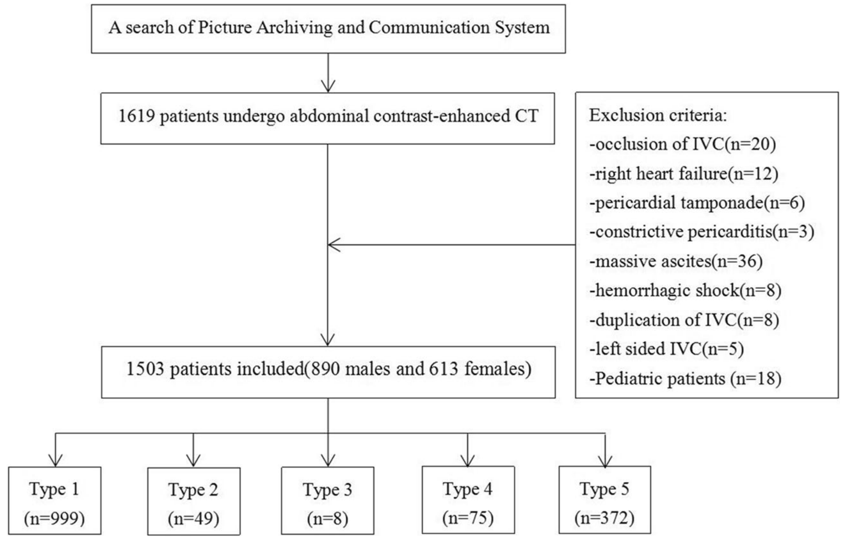

Fig. 1 Diagram of the study population

Results

Distribution of caval types on cross-sectional imaging

In our entire cohort of 1503 patients, there were 999 patients with type 1 IVCs (66.5%), 49 patients with type 2 (3.3%), 8 patients with type 3 (0.5%), 75 patients with type 4 (5.0%), and 372 patients with type 5 (24.7%) (Fig. 4).

Diameter and circumference measurement

The PD and CD in the overall study population and within each subgroup are presented in Table 1. The PD was significantly larger than the CD (22.3 ± 3.5 vs. 20.4 ± 2.8, paired *t* test, $p < 0.001$) in the entire study population. The PD was also significantly larger than the CD in type 1 (22.2 ± 3.3 vs. 20.4 ± 2.6, paired *t* test, $p < 0.001$), type 4 (23.2 ± 3.0 vs. 20.6 ± 2.5, paired *t* test, $p < 0.05$), and type 5 (22.6 ± 4.2 vs. 20.2 ± 3.1, paired *t* test, $p < 0.05$) IVCs. However, in type 2 (21.3 ± 3.0 vs. 20.9 ± 2.8, paired *t* test, $p = 0.095$) and type 3 (18.4 ± 2.6 vs. 20.8 ± 2.5, Wilcoxon signed-rank test, $p = 0.112$) IVCs, there was no significant difference between PD and CD.

Fig. 2 Illustration of measurement. The anterioposterior projective diameter (PD) and the circumference of the IVC were measured by manual contouring on cross-sectional CT images

Analysis of consistency agreements

There was excellent inter-rater reproducibility of diameter and circumference measurements between the two reviewers, with CCCs of 0.947 (95% confidence intervals, 0.941–0.952) and 0.802 (95% confidence intervals, 0.783–0.819).

For PD measurements, there were 1421 patients with caval diameter measuring smaller than 28 mm, while 82 patients had caval diameter measuring greater than 28 mm. For CD calculation, there were 1493 patients with calculated caval diameter smaller than 28 mm, while only 10 patients had calculated caval diameter greater than 28 mm. Overall, there were 73 patients with PD greater than 28 mm but CD smaller than 28 mm, and there was only 1 patient with PD smaller than 28 mm but CD greater than 28 mm. The scatterplot of PD vs. CD showed that the PD was consistently larger than the CD in the overall study population, as well as in type 1, type 4, and type 5 IVCs. In type 2 and type 3 IVCs, the PD and CD showed no difference. The scatterplot of PD vs. CD was shown in Fig. 5.

Discussion

In the present study, we divided IVC into five types based on the caval morphology. Our study revealed that the distribution of IVC types among the five categories was oval (72.0%, 1082/1503), round (3.3%, 49/1503), or irregular (24.7%, 372/1503). This result indicated that most of the caval measurements on simulated cavogram might not reflect the true

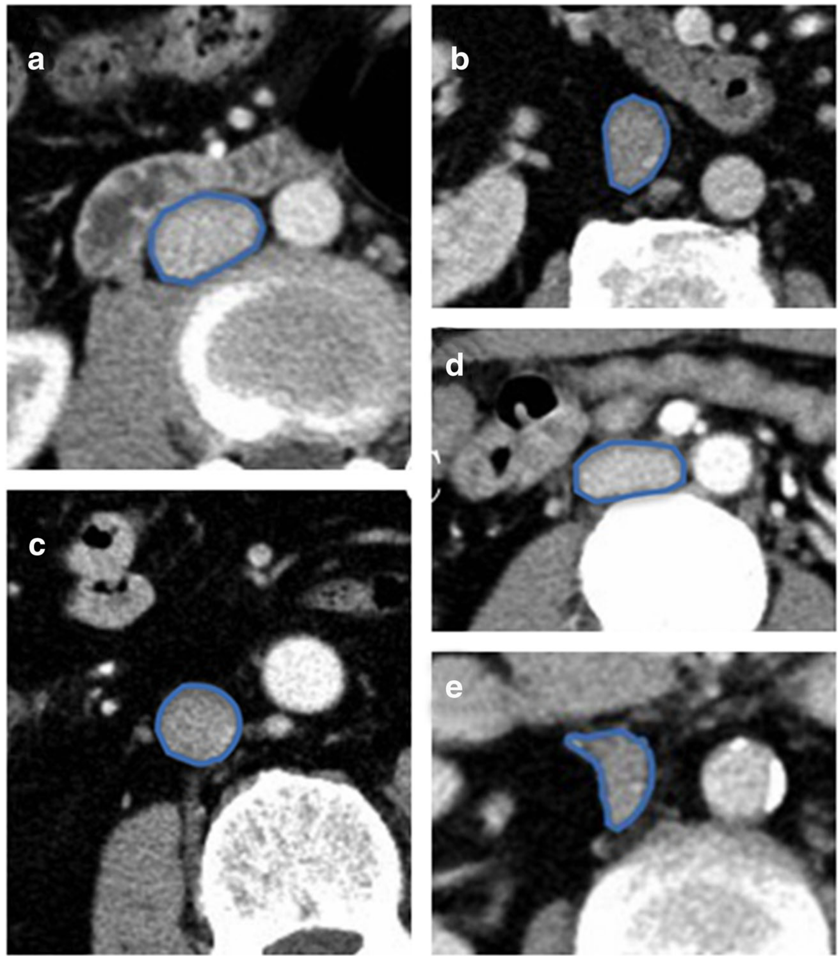

Fig. 3 The geometries and orientations of the IVC on cross-sectional imaging. Type 1 is an oval IVC oriented left-anterior-oblique to the horizontal line with an angle (**a**). Type 2 is a round IVC (**b**). Type 3 is an oval IVC with a vertical long axis (**c**). Type 4 is an oval IVC with a horizontal long axis (**d**). Type 5 is an irregular shape of IVC (**e**)

diameter of the IVC, because only 3.3% of the IVCs were round. Quantitatively, we showed that the average PD was always greater than the CD in the entire cohort, as well as in type 1, type 4, and type 5 IVCs. These discrepancies are likely due to the variable and frequently oblique caval orientation. There was no significant difference between the PD and CD in type 2 and type 3 IVCs. It was clear that the PD and CD were equivalent in type 2 IVCs, because the caval geometry in type 2 was round. For type 3 IVCs, the PD should have been smaller than the CD due to the vertical long axis of IVC. However, our results showed that there was no significant difference between the PD and CD in type 3 IVCs. This result could be attributed to the small sample size ($n = 8$) in this

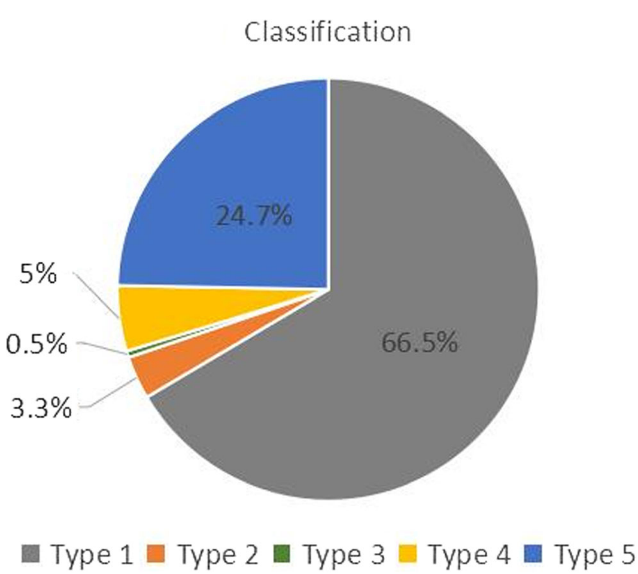

Fig. 4 Pie chart of the caval classification distribution

Table 1 PD and CD in overall study population and each subgroup

	PD	CD	*p* value
Overall ($n = 1503$)	22.3 ± 3.5	20.4 ± 2.8	$p < 0.05^{\#}$
Type 1 ($n = 999$)	22.2 ± 3.3	20.4 ± 2.6	$p < 0.05^{\#}$
Type 2 ($n = 49$)	21.3 ± 3.0	20.9 ± 2.8	$p = 0.432^{\#}$
Type 3 ($n = 8$)	18.4 ± 2.6	20.8 ± 2.5	$p = 0.115^{*}$
Type 4 ($n = 75$)	23.2 ± 3.0	20.6 ± 2.5	$p < 0.05^{\#}$
Type 5 ($n = 372$)	22.6 ± 4.2	20.2 ± 3.1	$p < 0.05^{\#}$

PD projective diameter, *CD* calculated diameter

Paired *t* test

*Wilcoxon signed-rank test

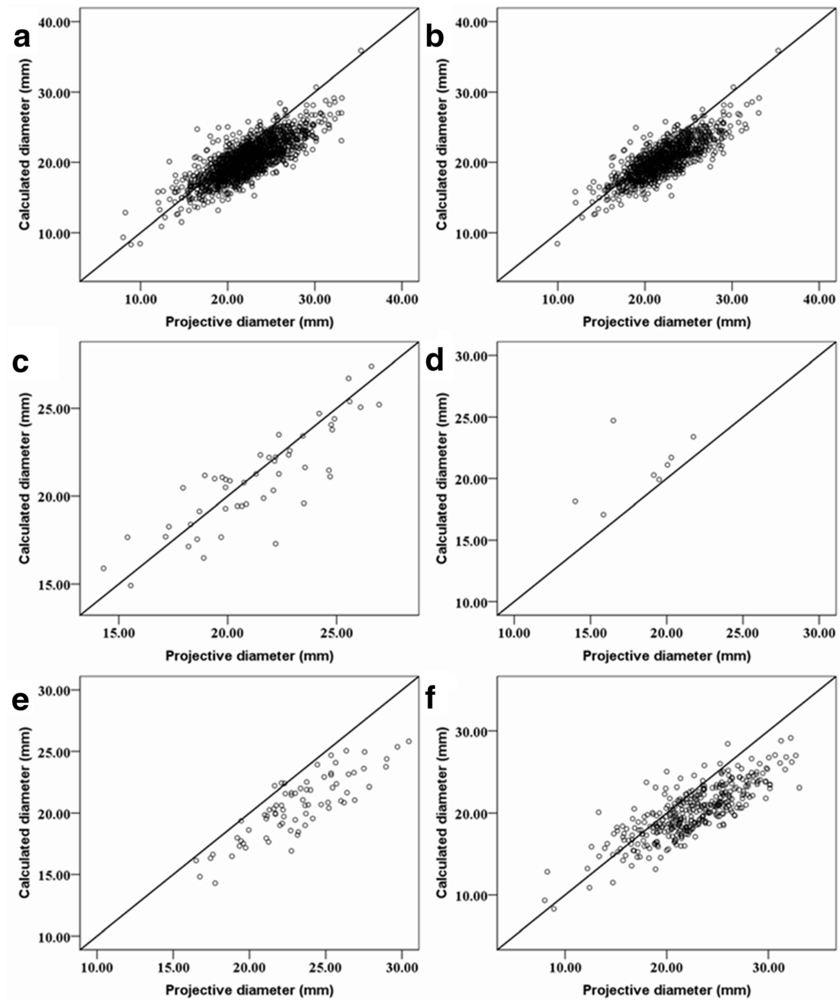

Fig. 5 Scatterplot of PD vs. CD in the overall study population (**a**) and within, type 1 IVCs (**b**), type 2 IVCs (**c**), type 3 IVCs (**d**), type 4 IVCs (**e**), and type 5 IVCs (**f**)

group, which might lead to sampling error. There were 73 patients with PD greater than 28 mm but CD smaller than 28 mm, which indicated that the PD measurement would have misidentified 73 IVCs as megacavas.

Since caval diameter determination is a crucial component of filter placement, several methods have been introduced for this issue including radio-opaque ruler method, calibrated intravascular catheter method, and 20% magnification rule method [11, 12]. However, they fail to demonstrate all five morphologies described in this study. As the IVC adopts a circular geometry once the filter is placed, the CD may be a proper approach for the exact measurement of the caval diameter. It should be noted that Kaura et al [10] investigated the circumference-based method for caval diameter determination. However, the results of their study were completely opposite to ours. They reported the PD was smaller than the CD (20.5 ± 3.7 vs. 23.0 ± 3.4), while our study showed a larger PD (22.3 ± 3.5 vs. 20.4 ± 2.8). A possible explanation for this discrepancy may be owing to the different measurement method. In their study, the caval circumference was measured by mapping the circumference of each cross-section to a straight line by carefully tracing the IVC circumference against the straight edge of a piece of paper, pivoting the edge at any curvature, while in the present study, the caval circumference was measured by manual contouring on cross-sectional CT images. In the previous study, pre-procedural CT was recommended as a routine in filter placement due to a higher sensitivity than that of cavogram in the detection of vessel variation [10, 12]. The present study showed that pre-procedural CT could provide added value of determining the caval diameter besides the detection of vessel variants. Although to date, there is no clinical practice guideline recommending pre-procedural CT in filter placement, we believe that a CT scan is necessary in filter placement. The incidence of megacava based on previous studies varies from 2 to 12% [3, 13, 14]. However, in our study, only 0.67% patients had megacavas based on the CD method. This discrepancy indicates that some of the "megacavas" may not truly exist, which may bias filter selection. Although a megacava is extremely rare, we believe that a pre-procedural CT needs to be performed routinely because insertion of an inappropriate filter might result in severe consequences such as migration or perforation.

There are several limitations in our study. First, our study did not directly investigate the incidence of filter migration or perforation, which is one of the most clinically significant issues in filter placement. Further studies should be conducted to investigate the frequency of incorrect filter choice according to the PD or CD measurements. Second, we did not use cone-beam CT to measure caval circumference. Since caval status on CT table and interventional table changes rapidly, especially in patients with trauma or PE, we believe that cone-beam CT may be an appropriate option for caval size determination. Further studies should be conducted to show the feasibility of cone-beam CT in filter placement. Third, we did not focus on the caval diameter measurement in patients with hemodynamic changes. As hemodynamics influences caval diameter, such patients are more likely to need an accurate estimation of caval size. Further studies are needed to separately measure the caval diameter in patients with or without hemodynamic compromise.

In conclusion, since it has been demonstrated that the IVC adopts a circular shape, measurement of CD may be better to assess maximum IVC diameter compared with PD for the purpose of IVC filter placement.

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Compliance with ethical standards

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Statistics and biometry No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was obtained from all subjects (patients) in this study.

Ethical approval Institutional Review Board approval was obtained.

Methodology
• retrospective
• cross sectional study
• performed at one institution

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