Inferior Vena Cava Filter Blockage: A Study on the Pressure Gradient across a Greenfield Filter

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1. Introduction

Pulmonary embolism (PE), which is one of the most severe complications of venous thromboemboli disease, is diagnosed in 355,000 patients and results in as many as 240,000 deaths each year in the United States [1]. PE occurs when a blood clot formed in a vein breaks free, becomes an embolus, travels to the lungs, and blocks pulmonary blood vessels.

Emboli that cause PE are most often developed in the deep veins within the legs as a result of poor circulation or damaged veins. The inferior vena cava (IVC) returns the blood from the lower extremities, pelvis, and abdomen to the heart’s right atrium. By placing a filter in the IVC, emboli may be captured before they travel to the heart. The placement of an IVC filter is considered standard preventive treatment for PE.

One common complication with IVC filters is the obstruction of blood flow when emboli are captured. To assess how the blood flow in the IVC is inhibited by an IVC filter, the pressure gradient across the filter must be considered. In this study, calculations have been completed to determine the pressure gradient across a Greenfield IVC filter. Various IVC diameters and embolus sizes are considered.

2. Calculations

The calculations for the pressure gradient across a Greenfield IVC filter are based on the conservation of energy. The major and minor head losses, kinetic energy loss, and potential energy loss are determined by IVC flow characteristics, IVC size, filter dimensions, embolus size, and the properties of blood.

Variation in the pressure gradient is driven by changes in velocity and the major head loss. The entrance velocity remains constant, even when the IVC diameter is changed. The exit velocity and the head loss vary as the emboli size and IVC diameter are altered. Both parameters are inversely related to the IVC diameter and directly related to embolus volume. This results in an increase in the pressure gradient when the IVC diameter is decreased or the embolus size is increased.

As previously noted, a range of IVC diameters and embolus sizes is considered. The IVC diameter was varied from 1.3 cm to 3.0 cm to reflect the range in human IVC diameters [2]. The volume of the embolus is varied from 0 to 6 cm³. This volume reflects the total emboli volume captured in the IVC filter, which may consist of several small emboli or one large embolus. The average size of emboli and average number of emboli captured in patients is uncertain. Emboli sizes used in experiments ranged from 2 mm in diameter and 10 mm long to 7 mm in diameter and 100 mm long [3][4]. If only one embolus of the given sizes is considered, the range in volume is .03 cm³ to 3.85 cm³.

Assumptions about the flow are made to apply the conservation of energy. The following are assumed: Newtonian fluid, laminar flow, incompressible, no slip at the wall, steady flow, rigid wall, fully developed flow, straight flow, circular cross section, and constant cross section. Assuming steady flow is the only assumption that greatly deviates from the natural behavior of the IVC, since the flow in the circulatory system is pulsatile. However for the purpose of this study, the simplified method of steady flow is reasonable.
3. Results

Figure 1 displays the results of the calculations. The pressure gradient increases when either the embolus volume increases or the IVC diameter decreases. In the smaller diameter IVC, the pressure gradient increases drastically even with small emboli. In comparison, the larger diameter IVC can capture a larger volume of emboli before the pressure gradient begins to significantly increase.

To assess the validity of the results, a comparison to experimental data was considered. The points on figure 1 designated with an ‘x’ are data points from Katsamouris et al [3]. The pressure measurements across a Greenfield IVC filter were taken in an experimental representation of a 2.3 cm diameter IVC with pulsatile flow.

4. Discussion

Calculating the pressure gradient across the IVC Greenfield filter produces results similar to that obtained experimentally by Katsamouris et al [3]. The difference between the experimental results and the calculations may be attributed to error within the assumptions. Further study on the effects of the assumptions and a more extensive comparison to experimental data is required to determine the error in the calculations.

Further study may also include performing pressure gradient calculations on a variety of IVC filter designs to assess how the filter design affects IVC blockage.

5. Conclusion

The pressure gradient calculations on the Greenfield IVC filter clearly indicate that the pressure gradient drastically increases when an embolus is captured in a small diameter IVC. This confirms that an individual with a small diameter IVC will be at high risk for IVC obstruction. Therefore, the patient’s IVC diameter should be considered prior to filter placement. The results also indicate that individuals with larger IVC diameters have a lower risk of IVC blockage since the pressure gradient does not increase as rapidly when small emboli are present. Although the risk of blockage is lower, larger IVC diameters have higher risk for other IVC filter complications. Such complications include filter tilt, migration, and reduced ability to capture emboli [4].