

RESEARCH LETTER

Impact of Renal Bridging Stent Tortuosity and Length on Stent Thrombosis using Flow Velocity Field Analysis[☆]

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Complex endovascular aortic aneurysm repair using branched endografts (B-EVAR) is becoming increasingly common. Renal bridging stent graft (BSG) occlusion caused by in stent thrombosis is a major concern due to the significant risk of subsequent chronic kidney disease development.¹

Previous studies have attempted to correlate the BSG configuration with the outcome after B-EVAR. In a study of 49 patients with 90 renal artery reconstructions, Sugimoto *et al.*² showed that high tortuosity was a significant predictor of renal branch occlusion, but along with renal angulation and the extent of renal coverage, BSG length was not. However, a recent study by Piazza *et al.*,³ including 32 patients with 123 directional renovisceral branches, suggested a significant linear relationship between BSG length and tortuosity ($p < .001$). Taken together, these findings indicate that there is a degree of ambiguity about the association between BSG length and the risk of in stent occlusion.

The significance of the BSG configuration on blood flow dynamics and in stent thrombus formation is still not fully understood.⁴ If the surface of the BSG path is curved rather than straight, the flow velocities will change along the surface. In addition, the velocity of blood flow changes differentially between its discrete blood flow layers, thereby generating a tangential force between them, termed shear stress. When there is velocity shear between the flow layers, Kelvin–Helmholtz (KH) instability occurs. Once KH instability reaches a critical point, vortex formation with turbulence takes place as the disturbed flow energy is transferred into rolling up the interface between flow layers. Turbulent energy and strong shear stress contribute to platelet activation and aggregation.⁵ It was hypothesised that tortuosity induced velocity shear alterations might explain the in stent thrombosis risk associated with renal BSG configurations.

One commonly accepted method to produce high resolution fluid velocity fields is a particle tracing technique using computational flow dynamics (CFD), which can simulate the behaviour of platelets. In the present study, velocity field data were extracted from CFD simulation of BSG geometry derived from post-operative computed tomography scans. The line integral convolution algorithm was used for velocity field visualisation, and the impact of the morphology of renal BSG paths on in stent flow characteristics was analysed, with a focus on the evolution of vortex structures.

Data from 13 patients with thoraco-abdominal aortic aneurysms treated with four vessel B-EVAR using custom made Cook stent grafts (Cook Medical, Bloomington, IN, USA), with varying configurations from standard straight or curved to ballerina positions, were analysed (13 right and 13 left renal BSGs; median BSG length 9.7 cm, interquartile range 7.2, 11.8 cm). The primary outcome from velocity field analysis was the magnitude of the tortuosity index (TI) related to the evolution of vortex structure. The TI was defined as the ratio of total BSG length over the shortest distance between the distal end of the branch cuff and the distal end of the BSG.⁶

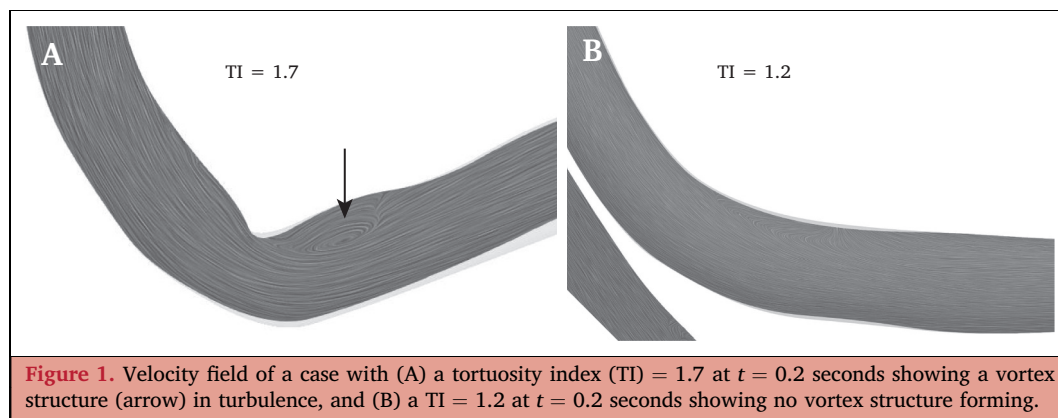
A major finding of the velocity field analysis was that velocity shear layers shifting towards instability were observed when mean TI was > 1.38 and vortices with turbulence developed when mean TI was > 1.46 at the site of bending (Fig. 1A). These features did not present in mildly angulated BSG paths (TI < 1.38) (Fig. 1B), showing that the increased TI due to bending of the BSG is responsible for flow disruption and vortex formation. Additionally, binary logistic regression involving KH instability with vortex formation on the TI showed that the TI had a statistically significant impact on vortex formation ($p = .035$). Further, there was no significant difference in BSG lengths between cases with KH instability occurrence and those without.

Consistent with Piazza *et al.*,³ the current study found a moderate positive correlation between renal BSG length and TI ($r = 0.67$; $p < .010$). However, since tortuosity is 3D whereas length is one dimensional, TI is more reflective of the complexity of a BSG path (that has a significant impact

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on in stent blood flow) than the total distance travelled along it.

This can be further explained in terms of velocity shear gradient momentum. A flow through a highly angulated BSG path experiences significant velocity shear changes over a short length. The larger the velocity shear gradient, the greater the momentum transfer between flow layers, generating KH instability. On the other hand, with a mildly angulated BSG path, the velocity shear gradient remains uniform or minimal throughout the flow path, regardless of length, rendering the BSG length itself not as crucial a factor in predicting in stent occlusion risk.

The current study was limited in its design to specifically investigate the effects of renal BSG path length and tortuosity on in stent flow characteristics, while other factors of possible importance, such as BSG diameter and type and operator dependent strategy, were not included. Furthermore, the low event rate exposes the study to risk of type II statistical error, which should be taken into account.

In conclusion, velocity shear gradient momentum, which is primarily influenced by TI but not by length, may clarify the ambiguity surrounding the association between BSG length and in stent occlusion risk. This suggests that highly angulated BSG paths should be avoided, even if this requires a longer path for the BSG.

CONFLICT OF INTEREST AND FUNDING

None.

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Bridging stent graft length, In stent occlusion risk, Renal bridging stent graft, Tortuosity index, Velocity shear gradient

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