INVITED COMMENTARY

Computational Modelling of Contemporary Stent-Grafts

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Since first reported in 1996,[1] there has been an ever increasing use of fenestrated (FSGs) and branched stent-grafts (BSGs) to repair abdominal aortic aneurysms (AAA). Such stent-grafts overcome the previous problem facing clinicians where the aneurysmal sac is either too close to the branching arteries and there is not enough healthy, thrombus-free aorta to create a secure and durable proximal seal (typically ≥15 mm is required), or the aneurysmal sac extends into the visceral segment. Fenestrated or branched devices allow stent-grafts to be placed between areas of aorta which are suitable for a seal while maintaining perfusion to the kidneys and gut, and are therefore highly desirable in cases of complex or unfavourable anatomy.

However, these devices introduce several new challenges; mainly regarding the orientation of the branches and their impact on the haemodynamics. Affecting the hemodynamics has implications for device durability, visceral perfusion and ultimately, the prognosis of the patient. Although the exact mechanisms are not fully understood, placement of stents in the aortic branches has been reported to alter the hemodynamics which can result in stent thrombosis.[2] The introduction of complex structures such as FSGs and BSGs into the blood flow, may even lead to the development of the biochemical thrombosis cascade.[3,4] It is therefore highly detrimental to configure a device in such a way that may promote thrombosis within the graft or branches, or reduce the perfusion through branches and fenestrations. In the article by Kandail et al.[5] they model the blood flow through many different configurations of FSGs and BSGs, and address two key questions by investigating flow rates, flow recirculation zones (FRZ) and displacement forces on the stent-graft: (a) how does the orientation of the branch (i.e. antegrade or retrograde) effect the flow through the renal arteries, and (b) what is the impact of visceral take-off angle (ToA).

In their report, they design a study that accounts for many of the likely configurations encountered during repair and perform computational fluid dynamics (CFD) simulations for each configuration. Three dimensional idealised stent-graft geometries were constructed with variations in ToA. For each ToA, they created antegrade and retrograde conduit geometries. Intuitively, antegrade seems like the better option if one is concerned with increasing flow through the conduit, however, a previous report that used CFD to investigate antegrade and retrograde configurations[6] showed this is not the case, as a retrograde configuration provided equal flow rate, especially in lengths applicable to branched AAA stent-grafts. Kandail et al.[5] have built on this foundation but instead, in their geometries, demonstrated that retrograde BSGs underperform in terms of flow to the renal arteries, compared to antegrade BSGs and FSGs, in all ToAs investigated. The retrograde BSGs also supplies less blood to the kidneys when the neck angle is 60°. The flow rate results of the authors (see Table 1 from Kandail et al.[5]) indicate that "renal flow in retrograde BSGs is sensitive to ToA, and an acute ToA (eg, 30°) tends to reduce renal flow; however, the quantitative effect of ToA on mean renal flow is relatively minor."

Furthermore, the authors investigate FRZ within the renal arteries, which are associated with low wall shear stress (WSS), and thus may be responsible for thrombus development, which may progress to occlusion and loss of renal function. The authors have adapted a previous method to detect separation lines in CFD simulations[7] that could have much use within the field. They demonstrate that in a planar geometry, the FRZs in antegrade and retrograde BSGs are typically larger than in FSGs, and the size of the FRZ in BSGs depends on the ToA. However, in angled neck geometries (the arguably more realistic situation), the FRZs were, unsurprisingly, different in each renal artery, favouring better flow in straighter branch points. Nonetheless, the FRZ in an angled neck is still quantitatively comparable to those found in straight-neck cases (see Figure 4 from Kandail et al.[5]).

Finally, Kandail et al.[5] quantify the displacement forces acting on all the stent-grafts. They show that the displacement force is dependent on the ToA but not the type of device. Displacement force increases almost linearly with increasing ToA. However, when the aortic neck angle was increased to 60°, the displacement force more than doubled (1.7 N to 3.6 N for a ToA of 90°), indicating that the neck angle is more critical than ToA in terms of displacement forces.

What we can note is the potential to use this study as a platform to build upon. There are certain limitations to the study design and computational modelling that represent an opportunity for others. Firstly, the authors have designed the study well and used realistic geometric configurations. Yet, many more configurations are possible with, for example, variations in the angle of the neck or increases in the ToA. By designing a fully parameterised study, we can potentially predict the flow patterns and phenomena in the many possible situations. Additionally, although there may be little room for improvement in the CFD methodologies, one could vary the inflow waveform to resemble several different situations likely to occur, such as increasing and decreasing the flow rates and varying the form of the flow rate to the models. Also, a recent investigation into the number of cardiac cycles required to achieve robust convergence of CFD simulations has identified that more than three cycles may be needed.[8] In this paper,[5] as is common in many previous reports,[9-12] data was deemed repeatable from the third or fourth cycle onwards. Additionally, the use of additional quantities such as vortical structures and particle residence time (PRT) may be particularly useful here. PRT has been used to model monocyte deposition in AAA,[12] shown to correlate with thrombus development in both aortic aneurysm[13] and aortic dissection,[14] and might be worthwhile to investigate in stent-grafts. PRT within various configurations of FSGs and BSGs may help elucidate the hemodynamic differences due to device configuration. Another limitation of this study is the generation of idealized 3D models of stent grafts to represent realistic anatomical morphology. Furthermore, for BSGs, the length of renal stents could extend more than 15 mm inside the main stent grafts, as reported in previous studies.[15,16] Thus, further research is suggested to simulate different lengths of BSGs based on patient-specific models.

Nowadays we see fenestrations and branches used with increasing frequency in complex reconstructions of the thoracic aorta involving chimneys, periscopes and snorkels. In some instances these devices are custom-made by manufacturers; designed by the clinician during the pre-surgical planning stage; or even in emergency situations, created at the bedside during the surgery. The clinical innovation is commendable, however many of these devices are designed without knowledge of the resulting haemodynamics. There is no doubt that these devices can allow vital flow to the branching vessels, but the question is: does the resulting haemodynamics cause thrombosis in the surrounding aneurysmal sac which is not excluded in the usual way, or in the device itself, and if not, does this result in procedural or device failure? The short-term data suggests not,[17] however, only time will tell if this is a both a real innovation and a safe one. As shown with the FSGs and BSGs examined here, computational modelling could help clinicians in the planning stage to design new devices with a complete appreciation of the impact the device will have on the flow and any potentially undesirable complications that may occur in the visceral arteries due to the device configuration, both in the short term and in the longer term after sac shrinkage.

In summary, the authors have shown that the hemodynamic effect of both FSGs and BSGs on the renal arteries is insignificant, indicating the safety of these stent-grafting procedures. Their findings are also consistent with a previous report on the minimal interference of fenestrated stent grafts with the renal blood flow.[18] Further studies based on patient-specific modelling with simulation of different lengths of BSGs and subsequent effects on renal flow patterns are recommended.

Acknowledgements

The authors gratefully acknowledge the National Health and Medical Research Council (Grants APP1063986 and APP1083572).

Conflicts of Interest

None.

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