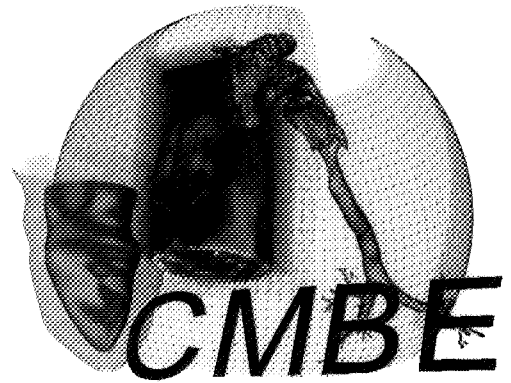


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SwirlGraft versus conventional straight graft as vascular access: a full CFD-analysis

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SUMMARY

Two 3D models of an arterio-venous graft, a connection between an artery and a vein as vascular access for hemodialysis, were studied. One model of a conventional straight loop graft, the other of a graft with helical configuration (e.g. SwirlGraft (Veryan Medical, London, UK)). The statement that the helical design reduces Intimal Hyperplasia (IH) formation was studied by evaluating low wall shear stress and high oscillatory shear stress zones next to the helicity flow index. The IH-inducing zones were reduced but were not eliminated and the helicity of the flow was increased. The statement that the SwirlGraft avoids stenosis should however be considered with care in clinical practice.

Key Words: arterio-venous graft, vascular access, CFD, shear stress, helicity.

1 INTRODUCTION

Constructing an arterio-venous graft is one of the choices for long-term vascular access in patients on hemodialysis as renal replacement therapy. This alternative to an arterio-venous fistula (direct connection between artery and vein), mostly used in patients with low quality vessels, has however a high complication rate. Thrombosis due to underlying stenosis account for 80% of graft failure [1]. These stenoses mostly occur at the venous anastomosis or in the draining vein. Stenoses at the venous anastomosis are originated from intimal hyperplasia (IH). The hemodynamic phenomenon of flow disturbance is known as an inducing factor [2]. This can be linked to low Wall Shear Stress (WSS), high oscillatory shear stress [3] or helicity of the bulk flow [4]. The SwirlGraft (Veryan Medical, London, UK) claims to reduce IH formation by adding a swirl to the conventional straight graft. This statement is assessed in a full Computational Fluid Dynamics (CFD) model, including artery, loop graft and vein.

2 MATERIAL AND METHODS

Two full 3D models were constructed in a parametric way, using pyFormex (pyformex.org):

- Straight conventional loop graft,
- SwirlGraft in loop configuration.

In both models (Figure 1), an artery with 4mm diameter and a vein of 6mm diameter, both 115 mm proximal and 45 mm distal length, were connected with a graft with a 45° anastomosis. The graft had in both cases a diameter of 6mm and a length of 300 mm. The SwirlGraft has a pitch of 70 mm and an amplitude of half the diameter.

Robust mesh sensitivity analysis was performed on the fully conformal structured hexahedral mesh to achieve results with less than 1% error on the WSS values. For the non-constant inlet case, a mesh of 1.3 million cells was used. The mesh was refined to a 3.3 million cell count to achieve reliable results for the non-constant inlet case. Both cases were calculated using Ansys Fluent 12 (ANSYS inc., Canonsburg, PA, USA), with double precision and unsteady (200Hz, even for the constant inflow).

With both models, two cases were calculated. One with a constant inflow of 600ml/min and one with a physiological relevant non-constant inflow (264-1500 ml/min, average 600ml/min, 60bpm), both with a parabolic inlet profile. The distal artery and distal vein outflow was set to 5% and the flow through the proximal vein was then the other 90%. A shear thinning viscosity model (Quemada) and a fluid density of 1054 kg/m³ were used.

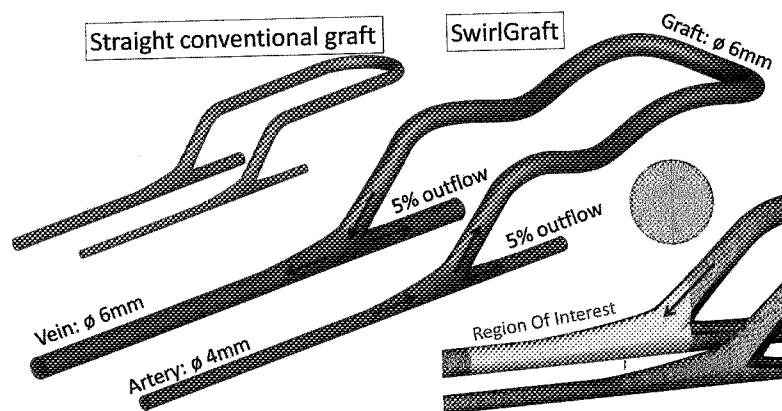


Figure 1: Overview: Two full 3D models, details of conformal hexahedral mesh and primary dimensions

The Region Of Interest (ROI) was defined at the venous anastomosis from 8 mm distal to 45 mm proximal to the center of the anastomosis, as shown in Figure 1. In this ROI, the average WSS (WSS_{avg}) and the Oscillatory Shear Index (OSI) were calculated. The WSS_{avg} was calculated from the constant inflow case:

$$WSS_{avg} = |\overline{WSS}| \quad (1)$$

The OSI was calculated for the physiological inflow:

$$OSI = \frac{1}{2} \times \left(1 - \frac{\left| \int_0^T \overline{WSS} \cdot dt \right|}{\int_0^T |\overline{WSS}| \cdot dt} \right) \quad (2)$$

The areas with low WSS_{avg} and high OSI were calculated in the ROI.

Next to these factors, the helicity (H) and the normalised helicity (ψ) of the flow were evaluated, calculated from the Velocity (V):

$$H = V \cdot (\nabla \times V) \quad (3a)$$

$$\psi = \frac{H}{|V| \cdot |\nabla \times V|} \quad (3b)$$

By calculating the Helicity Flow Index (HFI) [4], the helicity could be evaluated in a Lagrangian way:

$$HFI = \frac{1}{N_p} \sum_{i=1}^{N_p} \frac{1}{N_k} \sum_{j=1}^{N_k} |\psi_{ij}| \quad (4)$$

with N_p pathlines with each N_k points. In this study, the pathlines starting in the graft at 42 mm from the anastomosis side were used. For our analysis, 169 paths (N_p) with each 300 steps (N_k), covering the whole ROI, were used.

Post-processing was performed in Ansys Fluent 12, Matlab 7.8.0.347 (MathWorks inc., Natick, MA, USA) and Tecplot 360 2010 (Tecplot inc., Bellevue, WA, USA).

3 RESULTS

Figure 2 shows the WSS (left) and the OSI (right) for the region of interest. Zones with low WSS and high OSI are located at the upper ceiling of the anastomosis and at the heel (entrance of distal artery) for both cases.

Areas of low WSS and high OSI are shown in Table 1. A reduction of the area with low WSS and high OSI can be found comparing the SwirlGraft to the straight conventional graft. In Table 2, the results for the HFI are shown. A increase in the helicity can be found when a swirl is introduced in the graft design.

in ROI	Conventional graft	SwirlGraft	Area reduction
WSS \leq 0.6 Pa	1.04 cm ²	0.77 cm ²	26 %
WSS \leq 0.5 Pa	0.86 cm ²	0.60 cm ²	31 %
WSS \leq 0.4 Pa	0.67 cm²	0.43 cm²	35 %
OSI \geq 0.3	1.16 cm ²	0.84 cm ²	42 %
OSI \geq 0.2	0.51 cm ²	0.39 cm ²	24 %
OSI \geq 0.1	0.25 cm²	0.15 cm²	28 %

Table 1: Areas with low WSS and high OSI in ROI

	Conventional graft	SwirlGraft	Increase in Helicity
HFI	0.282	0.313	11 %

Table 2: Values for the Helicity Flow Index (HFI)

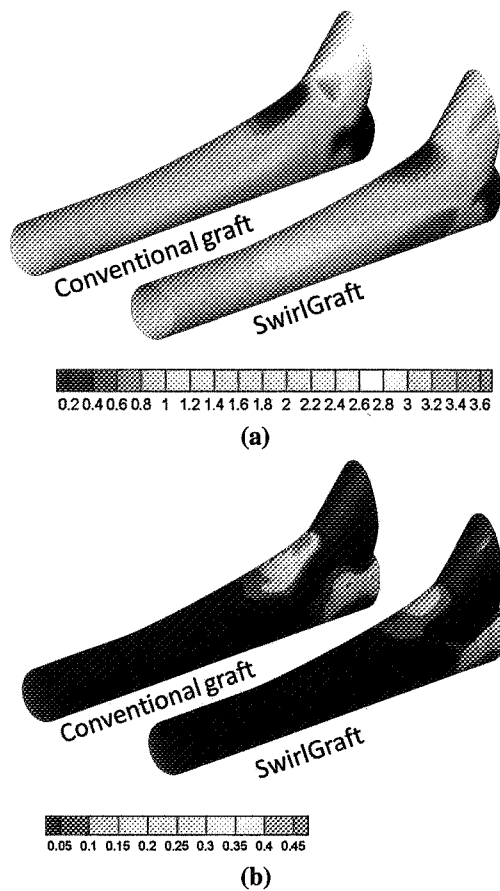


Figure 2: WSS [Pa](a) and OSI (b)

4 CONCLUSIONS

The SwirlGraft effectively reduces low WSS and high OSI zones, but does not eliminate them. The reduction of WSS temporal gradients can be linked to the increase in HFI as suggested by Morbiducci et al. [4]. The statement that the SwirlGraft avoids stenoses should however be considered with care in clinical practice.

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