Spiral Laminar Flow
The Evidence

Section D:
In Vitro, Animal and Scientific Studies

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1. Computational comparison of spiral and non-spiral peripheral bypass grafts

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Introduction

A peripheral vascular graft is used for the treatment of peripheral arterial disease. Restenosis in the distal anastomosis is the main reason of occlusion and is related to haemodynamics. Single spiral flow is a normal feature in vessels.
A graft designed to generate a single spiral in its outflow (VFT Ltd, Dundee, UK) has been introduced in clinical practice. This study compared the spiral graft with a control non-spiral using image-guided modelling.

Methods

Both grafts were housed in ultrasound flow phantoms. Anastomotic angle θ was applied at 20°, 40°, 60° and 80°. The phantoms were scanned with CT (Biograph mCT, SIEMENS, Germany) and the graft-vessel mimic lumen geometry was extracted with Amira (FEI Visualization, France).
Based on these geometries volume meshes were created (ICEM CFX, ANSYS, Canonsburg, USA), which consisted of tetrahedral cells in the core and prismatic cells in the wall boundary.
Mesh independence tests were applied based on maximum wall shear stress and velocity. The blood was assumed Newtonian, homogeneous and incompressible, the walls rigid and the inflow a steady parabola (Reynolds 620, 935).
The Navier-Stokes governing equations of flow were solved with ANSYS CFX. Fluid dynamic parameters were compared between the spiral and corresponding non-spiral models focusing on the flow downstream of the anastomosis.
The vortical structures at cross-flow patterns 1-4 had previously been studied experimentally with ultrasound vector Doppler imaging, which was used for validation.

Results

The presented results are for θ = 40°. A single spiral was the main characteristic in the outflow of the spiral graft and a double or triple spiral in the outflow of the control.
The maximum in-plane velocity (perpendicular to flow direction) at cross-flow planes 1 – 4 was constantly higher for the spiral graft model.
The total circulation in cross-flow planes 1 – 4 was higher for the spiral graft model particularly for increased Reynolds.
Helicity in the volume between cross-flow plane 1 and 4 was higher for the spiral model. The pressure drop over length from the graft inlet to cross-flow plane 4 was reduced for the non-spiral graft model.
The wall shear stress (WSS) was examined in proximal and distal locations of the floor and toe wall centrelines. The WSS was higher for the spiral graft model in all tested locations. The results from θ = 20°, 60°, 80° were comparable.

Discussion

The flow pattern generated by the spiral graft was related to less flow separation, stagnation and instability than that induced by the control graft.
The increased in-plane velocity, circulation and helicity of the spiral device showed increased in-plane mixing, which has been reported to protect endothelial function.
Pressure drop is not desirable. The detected difference in pressure loss can be assumed negligible because the physiologic pressure is in the range of 1 – 20 × 104 Pa.
Increased WSS is considered atheroprotective, although this may not apply in the proximal floor where the blood impinges abnormally on the wall of the host vessel.

Conclusions

The spiral graft was able to reintroduce a single spiral pattern in its outflow, associated with flow coherence downstream of the host vessel and high intensity cross-flow phenomena. Such local haemodynamics are known to prevent neointimal hyperplasia and thrombosis. These results support the hypothesis that spiral grafts may improve the patency rates in patients.

2. Is the structure of the vessel wall a generator of Spiral Flow? A Cadaveric histological study

IN ABSTRACTS FROM VAS 8TH INTERNATIONAL CONGRESS, APRIL 25-27, 2013 PRAGUE, CZECH REPUBLIC. J VASC ACCESS 2013; 14(1): 5
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Background

In healthy individuals flow patterns in the arterial tree have a spiral vector (Spiral laminar flow, SLF) which is attributed to the eccentric myocardial action and the spiral nature of the aortic arch.

Previous studies have shown that SLF is present within health and also within the arteries of patients with arteriovenous fistulas. This is disrupted through the swing segment yet is regenerated in the venous segment above this.

This pattern is present in AVFs immediately post operatively and is a predictor of superior outcome. This implies that veins are capable of generating spiral flow independently and that SLF may have physiological benefits.

The aims of this study were to assess the anatomical ultra structure of artery and vein with particular reference to muscle fibre orientation as a potential generator of spiral flow.

Materials and Methods

Using preserved cadaveric post-mortem tissue brachial artery and cephalic vein structure was assessed using an established technique to analyse nuclear orientation.

In brief sections were taken from vessels at two different angles allowing nuclear size to be assessed.

By correlating nuclear length and the incident angle of the section the orientation of muscle fibres was determined allowing the 3 dimensional arrangements of muscle fibres to be assessed.

Results

Using sectioning angles of 0˚and 20˚ randomly selected regions of tunica media within vessel sections were analysed. Maximum nuclear length was 18.26μm and 8.29μm at each angle respectively. This estimates an arterial smooth muscle pitch 6.04˚ to 6.28˚ of the muscular fibres using each section respectively.
Within veins the angle estimates are more variable with multidirectional arrangement and the muscle angle pitch estimated at 1.4˚ to 9.3˚.

Conclusions

Spiral flow grafts are a valid successful option for AV access. One year results are superior to using straight ePTFE and heparin bonded grafts.
This may be explained on the basis of the hemodynamic environment created by the spiral laminar flow and may be a significant contribution to preventing neointimal hyperplasia and hence AV access graft failure.

Discussion

The obliquity of muscle fibres within the vessels is consistent with Doppler ultrasound findings of spiral laminar flow in both artery and vein.
The central generation hypothesis of spiral flow is questioned by the clinical model of an AV fistula and this study supports the vessel wall as an independent peripheral generator of spiral laminar flow.

3. Hemodynamic differences in the outflow of access vascular grafts

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Background

Access vascular (AV) prostheses are commonly used for haemodialysis. Their low patency rates remain a challenge with restenosis in the distal anastomosis being the main reason of failure. The blood flow profile affects the wall shear stress which is a crucial factor for the endothelial function.

Single spiral flow has been found to be a normal physiologic characteristic of vascular blood flow. This study compared the Spiral Laminar Flow™ AV graft (Vascular Flow Technologies, UK) which is designed to induce spiral flow against a control AV device.

Materials and Methods

The prostheses were integrated in an in-house ultrasound flow phantom which was consisted of blood, vessel, tissue mimicking materials and a piston pump.

The devices were tested using a curve and straight configuration to mimic vascular surgical implantation geometries. Steady flow rates up to 720 ml/min were applied.

Colour Doppler ultrasound imaging was utilized in a number of cross-sectional planes distally from the grafts outflow.

To visualize and quantify rotational flow patterns, a vector Doppler technique was developed using Matlab (MathWorks, USA).

Two-dimensional velocity magnitude and directional maps were created and an analysis based on the magnitude of the peak radial velocity was performed.

Results

A single spiral flow was detected in the outflow of the spiral graft and two or three spirals in the outflow of the control device, for both types of anastomosis.

Flow separation and areas of stagnation were detected when more than one helix existed.
The radial velocity was consistently higher for the single spiral in comparison to that of the multi-spiral patterns under all the applied conditions.
The flow pattern under high flow rates was stable for the spiral graft and disturbed for the control device.

Conclusions

The single helical pattern created by the spiral graft was associated with increased magnitude of radial velocity. This is an index of increased wall shear stress which is considered atheroprotective.
These results support the hypothesis that spiral graft improves flow stability and coherence which may relate to increased graft patency rates.

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4. Haemodynamic effects of spiral ePTFE prosthesis compared with standard arteriovenous graft in a carotid to jugular vein porcine model

J VASC ACCESS. 2011 JUL-SEP;12(3):224-30. DOI: 10.5301/ JVA.2010.6097
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Introduction

The primary patency rate of arteriovenous (AV) grafts is limited by distal venous anastomosis stenosis or occlusion due to intimal hyperplasia associated with distal graft turbulence. The normal blood flow in native arteries is spiral laminar flow.
Standard vascular grafts do not produce spiral laminar flow at the distal anastomosis. Vascular grafts which induce a spiral laminar flow distally result in lower turbulence, particularly near the vessel wall.
This initial study compares the hemodynamic effects of a spiral flow-inducing graft and a standard graft in a new AV carotid to jugular vein crossover graft porcine model.

Methods

Four spiral flow grafts and 4 control grafts were implanted from the carotid artery to the contralateral jugular vein in 4 pigs.
Two animals were terminated after 48 hours and 2 at 14 days. Graft patency was assessed by selective catheter digital angiography, and the flow pattern was assessed by intraoperative flow probe and colour Doppler ultrasound (CDU) measurements.
The spiral grafts were also assessed at enhanced flow rates using an external roller pump to simulate increased flow rates that may occur during dialysis using a standard dialysis needle cannulation.
The method increased the flow rate through the graft by 660 ml/min. The graft distal anastomotic appearances were evaluated by explant histopathology.

Results

All grafts were patent at explantation with no complications. All anastomoses were found to be wide open and showed no significant angiographic stenosis at the distal anastomosis in both spiral and control grafts.
CDU examinations showed a spiral flow pattern in the spiral graft and double helix pattern in the control graft. No gross histopathological effects were seen in either spiral or control grafts.

Conclusion

This porcine model is robust and allows haemodynamic flow assessment up to 14 days post-implantation. The spiral flow-inducing grafts produced and maintained spiral flow at baseline and enhanced flow rates during dialysis needle cannulation, whereas control grafts did not produce spiral flow through the distal anastomosis. There was no deleterious effect of the spiral flow-inducing graft on macroscopic and histological examination. The reducing effect of spiral flow on intima hyperplasia formation will be the subject of further study using the same AV graft model at a longer period of implantation.

5. Structure/function interface with sequential shortening of basal and apical components of the myocardial band

EUROPEAN JOURNAL OF CARDIO-THORACIC SURGERY 29S (2006) S75-S97
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Objective

To study the sequential shortening of Torrent-Guasp's 'rope-heart model' of the muscular band, and analyse the structure-function relationship of basal loop wrapping the outer right and left ventricles, around the inner helical apical loop containing reciprocal descending and ascending spiral segments.

Methods

In 24 pigs (27-82 kg), temporal shortening by sonomicrometer crystals was recorded. The ECG evaluated rhythm, and Millar pressure transducers measured intraventricular pressure and dP/dt.

Results

The predominant shortening sequence proceeded from right to left in basal loop, then down the descending and up the ascending apical loop segments. In muscle surrounded by the basal loop, epicardial muscle predominantly shortened before endocardial muscle.
Crystal location defined underlying contractile trajectory; transverse in basal versus oblique in apical loop, subendocardial in descending and subepicardial in ascending segments. Mean shortening fraction average 18 ± 3%, with endocardial exceeding epicardial shortening by 5 ± 1%. Ascending segment crystal displacement followed descending shortening by 82 ± 23ms, and finished 92 ± 33 ms after descending shortening stops, causing active systolic shortening to suction venous return; isovolumetric relaxation was absent.

Conclusion

Shortening sequence followed the rope-like myocardial band model to contradict traditional thinking. Epicardial muscle shortened before endocardial papillary muscle despite early endocardial activation, and suction filling follows active systolic unopposed ascending segment shortening during the 'isovolumetric relaxation' phase.

6. Non spiral and spiral (helical) flow patterns in stenoses. *In Vitro* observations using spin and gradient echo magnetic resonance imaging (MRI) and computational fluid dynamic modelling Int Angiol. 2004 Sep;23(3):276-83.

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Aim

Physiological blood flow patterns are themselves poorly understood despite their impact on arterial disease. Stable spiral (helical) laminar flow has been observed in normal subjects. The purpose of the present study is to develop a method of magnetic resonance (MR) flow pattern visualization and to analyse spiral and non-spiral flow patterns with and without luminal narrowing *In Vitro*. The flow conditions were then modelled using computational fluid dynamics (Star-CD).

Methods

Laminar integrity was examined in a flow-rig using spin and gradient echo magnetic resonance imaging (MRI) in non-stenosed and stenosed conduits in the presence of non-spiral and spiral flow.

Results

No difference was observed in a non-stenosed conduit between non-spiral and spiral flow. In the presence of a stenosis spiral flow preserves flow velocity coherence whereas non-spiral flow increasingly lost coherence beginning proximal to the stenosis.
Computational fluid dynamic modelling of the *In Vitro* experiment showed marked differences between the 2 flow patterns. Non-spiral flow produced greater inwardly directed forces just beyond the stenosis and greater outward pressures at more distal sites.
The near wall turbulent energy was up to 700% less with spiral flow over non-spiral flow beyond the stenosis.

Conclusion

Spiral flow appears to offer clear flow profile stabilizing advantages over non-spiral flow, by significantly reducing the turbulence caused by a stenosis.
Spiral flow also produces lower forces acting on the vessel wall.

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7. The heart is not a pump: a refutation of the pressure propulsion premise of heart function

FRONTIER PERSPECTIVES, J CENTRE FRONTIER SCIENCES, TEMPLE UNIVERSITY, PHILADELPHIA, PA. 1995:VOL 5(1)
MARINELLI R, FUERST B, ZEE H, MCGINN A, MARINELLI W

Background

In 1932, Bremer of Harvard filmed the blood in the very early embryo circulating in self-propelled mode in spiralling streams before the heart was functioning. Amazingly, he was so impressed with the spiralling nature of the blood flow pattern that he failed to realize that the phenomena before him had demolished the pressure propulsion principle.
Earlier in 1920, Steiner, of the Goetheanum in Switzerland had pointed out in lectures to medical doctors that the heart was not a pump forcing inert blood to move with pressure but that the blood was propelled with its own biological momentum, as can be seen in the embryo, and boosts itself with “induced” momenta from the heart.
He also stated that the pressure does not cause the blood to circulate but is caused by interrupting the circulation. Experimental corroboration of Steiner’s concepts in the embryo and adult is herein presented.
