

## Spiral Laminar Flow

### The Evidence



### Section C:

#### *In Vivo* Human Studies

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# 1. Patterns of blood flow as a predictor of maturation of arteriovenous fistula for haemodialysis

J VASC ACCESS 2014;15 (3): 169-174 YAZIN MARIE<sup>1</sup>, ALISON GUY<sup>1</sup>, KAREN TULLETT<sup>1</sup>, HARI KRISHNAN<sup>1</sup>, ROBERT G. JONES<sup>2</sup>, NICHOLAS G. INSTON<sup>1</sup> DEPARTMENT OF RENAL SURGERY<sup>2</sup> DEPARTMENT OF INTERVENTIONAL RADIOLOGY QUEEN ELIZABETH HOSPITAL, UNIVERSITY HOSPITALS BIRMINGHAM NHS TRUST, BIRMINGHAM, UK

## Purpose

A palpable “thrill” is traditionally associated with success following arteriovenous fistula (AVF) surgery. A thrill typically characterizes turbulent flow and this is a paradox as turbulence is a driver of neointimal hyperplasia. Spiral laminar flow (SLF) has been described as normal and protective pattern of flow in native arteries and is associated with superior patency in bypass grafts that generate it. The aim of this study was to define the pattern of flow within AVFs immediately post-operatively and at follow-up to assess maturation.

## Methods

Doppler ultrasound was used immediately post-operatively and at follow-up (6 weeks). Blood flow was assessed as SLF or non-SLF. Two blinded qualified observers analysed the images. Patients were followed up for 6 months. Maturation was statistically analysed against the type of flow.

## Results

Sequential patients having AVF surgery (n=56) were assessed: 46 (82%) patients had a thrill, 3 patients had no flow and 7 patients had pulsatile flow without a palpable thrill. SLF was present in 80% of those with a thrill but not in any without a thrill ( $p<0.0001$ ). At follow-up (n=51) 41 patients had a matured AVF (80%), of which 76% had SLF immediately post-operatively. Only one patient with SLF failed to mature. In the non-SLF group 5 of the 15 AVFs failed to mature (66%;  $p<0.005$ ).

## Conclusions

SLF was strongly supportive of successful fistula maturation. A “thrill” was characteristic of spiral rather than turbulence. The mechanism of this apparent beneficial effect of this pattern of flow requires further investigation.

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## 2. The characteristic flow pattern of a “thrill” in Autologous AV Fistulae above the swing segment is spiral flow rather than turbulence

PRESENTED AT THE VASCULAR ACCESS FOR HAEMODIALYSIS XIII SYMPOSIUM, MAY 9-11, 2012, ORLANDO, FLORIDA, USANICK G. INSTON, MD, YAZIN MARIE, STEPHEN J. MALLOR, HARI KRISHNAN AND ROBERT JONES

### Objectives

In healthy individuals arterial blood flow has been characterized as having a spiral laminar pattern (Stonebridge P et al 1991). A loss of this pattern of flow is associated with pathology (Houston G et al 2004). It can be hypothesized that the effect of the spiral nature of flow is to maintain healthy physiologic levels of shear stress on endothelial cells. Pathological flow patterns and reduction of shear stress result in loss of atheroprotective mechanisms and promote pathology such as neointimal hyperplasia. The desired characteristic of a successful AVF is a thrill typically associated with turbulent flow. The aim of this study was to characterize the nature of flow in autologous AVF and assess spiral flow specifically.

### Methods

Using Doppler ultrasound both brachiobasilic and radiocephalic AVF were assessed in the peri-operative period for the characteristic flow patterns. AVFs were assessed immediately post-operatively at the swing segment and 5cm above the swing segment in vein that had not been operated on.

### Results

In patients with an immediate post-operative thrill (RCF n=10; BCF n=10) spiral flow was demonstrated within all fistulas in the vein above the swing segment. Within the swing segment flow was not spiral and had turbulent characteristics. The inflow artery in all cases demonstrated spiral flow.

### Conclusion

The demonstration of spiral flow in the non-operated segment of AVFs has major implications. The low incidence of stenoses within this segment supports the hypothesis that spiral flow is atheroprotective whereas turbulent flow is pathological. In addition the demonstration of flow changing from spiral flow in the artery to turbulent in the swing section and then restoration of spiral flow in the vein supports the vein ultrastructure as the mediator of spiral flow. The impact of spiral flow on AVF maturation and function is currently under investigation.

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### 3. The Presence of Spiral Laminar Flow in Autologous Arterio-venous Fistulae

POSTER AT THE VASCULAR ACCESS SOCIETY OF BRITAIN AND IRELAND SYMPOSIUM, SEPTEMBER 2011, BRIGHTON, UKGUTHRIE, SUTTIE, ROSS, LEVISON & STONEBRIDGE

#### Purpose

In non-atherosclerotic vessels, flow is predominantly 'spiral laminar' rather than laminar. Spiral Laminar Flow (SLF) stabilises flow patterns at regions of arterial branching. Non SLF at stenotic segments results in poor flow cohesion, increasing turbulence. SLF has been shown to prevent the development of renal and carotid artery stenosis. We aimed to determine if SLF is present in arterio-venous fistulae (AVF) and correlate this with flow limiting stenosis.

#### Methods

Patients attending routine duplex surveillance of their arterio-venous fistula for haemodialysis (September-November 2010), were assessed for SLF in the venous limb of their AVF. Data collected included: age; sex; type of AVF; primary AVF or not (fistula number); presence of flow limiting stenosis.

#### Results

We recruited 33 (15 male, 18 female) consecutive patients (mean age of 68 years, range 30-94 years). All AVF were autologous, 10/33 radiocephalic, 15/33 brachiocephalic and 8/33 brachio basilic with superficialisation and all were being utilised for haemodialysis at time of surveillance. The majority were primary fistulae (24/33), seven being secondary and two being tertiary AVF. SLF was identified in 31 of the AVF, with 10 noted to have non flow limiting stenosis.

Age, fistula type and fistula number had no significant impact on stenosis formation. Due to only two AVF without SLF, association between stenosis, age, sex, AVF type and number with SLF was not conclusive.

#### Conclusion

Spiral Laminar Flow is present in autologous arterio-venous fistula with no flow limiting stenosis. We continue to collect data to determine if Spiral Laminar Flow affects patency and flow of arterio-venous fistulae.

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## 4. Three-dimensional blood flow dynamics: spiral/helical laminar flow

METHODIST DEBAKEY CARDIOVASC J. 2011 JAN-MAR;7(1):21-6. STONEBRIDGE P.

Recent work in cardiac and peripheral vascular blood flow has shown evidence for an elegant complexity to flow within the heart and in the large to medium arteries. Blood flow is normally described as laminar in that the blood travels smoothly or in regular paths.

The velocity, pressure, and other flow properties at each point in the fluid remain constant, all parallel to each other. Our understanding has revolved around a two-dimensional representation of flow within three-dimensional blood vessels.

However, MRI and colour Doppler flow imaging techniques have demonstrated that there is a spiral/helical/rotational property to laminar blood flow. The column of blood turns on a central axis as it passes along the major arteries.

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## 5. Spiral laminar flow in the abdominal aorta: a predictor of renal impairment deterioration in patients with renal artery stenosis?

NEPHROL DIAL TRANSPLANT. 2004 JUL;19(7):1786-91. EPUB 2004 MAY 25

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### Background

Spiral or helical arterial blood flow patterns have been widely observed in both animals and humans. The absence of spiral flow has been associated with carotid arterial disease. The aim of this study was to detect the presence of aortic spiral flow using magnetic resonance imaging (MRI) and to evaluate the relationship of the presence of spiral aortic flow with renal arterial disease and renal function in the follow-up of patients with suspected renal atheromatous disease.

### Methods

Prospective study of 100 patients with suspected renal arterial disease and 44 patient controls. Using a 1.5 T MRI unit (Siemens Symphony), phase contrast flow quantification and three-

dimensional contrast enhanced MR angiography of the abdominal aorta were performed. Renal arterial stenoses (RAS) were classified minimal, moderate or severe. Renal function was followed at 3 months before and 6 months after MRI.

## RESULTS:

Non-spiral flow was more prevalent in patients with more severe RAS. Renal impairment progressed significantly in severe RAS without spiral flow ( $P = 0.0065$ ), but did not progress significantly in severe RAS with spiral flow ( $P = 0.12$ ). In minimal or moderate RAS with or without spiral flow there was no significant progression ( $P = 0.16, 0.13, 0.47, 0.092$ , respectively).

## Conclusion

Aortic spiral blood flow can be assessed with MRI. Lack of aortic spiral blood flow in patients with severe RAS is associated with significant short-term renal function deterioration. Determination of blood flow patterns may be a useful indicator of renal impairment progression in patients with suspected renal artery stenosis.

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## **6. Two-dimensional flow quantitative MRI of aortic arch blood flow patterns: Effect of age, sex, and presence of carotid atheromatous disease on prevalence of spiral blood flow**

J MAGN RESON IMAGING. 2003 AUG;18(2):169-74.

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### Purpose

To determine the effect of age, sex, and presence of carotid atheromatous disease on the presence of aortic spiral blood flow pattern using two-dimensional flow quantitative magnetic resonance imaging (MRI).

## Materials & Methods

Sixty subjects (37 women, 23 men) were examined. Prospective phase contrast flow quantitative MRI (1.5 T, Siemens Symphony) sequences in the plane of the aortic arch, and three-dimensional contrast-enhanced MR angiography of the vessels from the aortic arch to the circle of Willis, were performed. Flow quantitative analysis, using circular regions of interest, in the root, apex, and descending aortic arch to determine the presence of a spiral blood flow pattern was undertaken. The results were correlated with the subjects age, sex, and presence of significant carotid arterial disease.

## Results

A spiral blood flow pattern was seen during diastole in 43 of 50 (86%), 42 of 48 (88%), and in 26 of 28 (93%) subjects in the root, apex, and descending aortic arch, respectively. Spiral flow was seen during systole in 14 of 35 (40%), 20 of 47 (42%), and 11 of 31 (35%) subjects in the root, apex, and descending aortic arch, respectively. There was no clear effect of age or sex on the presence of spiral flow.

Carotid disease was associated with a significant reduction in the prevalence of systolic spiral flow from 51%-19% subjects ( $P < 0.05$ ). Conclusion Spiral flow pattern can be seen in the arch of the aorta in clinical practice using flow quantitative MRI. The prevalence of spiral flow pattern does not appear affected by subject age or sex. Carotid atheromatous disease is associated with a reduction in prevalence of systolic spiral flow pattern in the aortic arch.

## Conclusion

Spiral flow pattern can be seen in the arch of the aorta in clinical practice using flow quantitative MRI. The prevalence of spiral flow pattern does not appear affected by subject age or sex. Carotid atheromatous disease is associated with a reduction in prevalence of systolic spiral flow pattern in the aortic arch.

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## 7. 4D magnetic resonance velocity mapping of blood flow patterns in the aorta in young vs. elderly normal subjects

J MAGN RESON IMAGING. 1999 NOV;10(5):861-9. BOGREN HG, BUONOCORE MH.

### Abstract

Four-dimensional magnetic resonance MR velocity mapping was developed to study normal flow patterns in the thoracic aorta using time-resolved cardiac gated three-directional velocity data. Sixteen normal subjects were studied, one young group (average age 31 years) and one group with elderly people (average age 72 years). Blood flowed in a right-handed helix from the ascending aorta to the aortic arch. A straight flow pattern or a left-handed helix was seen in the descending aorta. Blood flow was never parabolic. Blood flowed forward in early systole, retrograde in mid-to-end systole, and forward again in diastole in all subjects as a basic pattern. Continuous retrograde flow over a long distance was not seen, but blood entered a retrograde flow column at various levels.

In young people blood passed from the aortic valve to the mid-descending aorta in less than one heartbeat. In people in their sixties it took two heartbeats and in people older than 78 years, it took three heartbeats.

The maximum systolic forward velocities were higher in young subjects than in elderly while the retrograde velocities were lower.

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## 8. Spiral laminar flow *in vivo*

CLIN SCI (LOND). 1996 JUL;91(1):17-21.

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Blood flow patterns are poorly understood despite their impact on arterial disease. There have been few measurements *in vivo* of the three-dimensional blood flow patterns; we present the results of such studies using a new non-invasive *in vivo* method of examining biplanar arterial blood flow patterns.

Multiple colour Doppler ultrasound directional velocity images were obtained at two different beam target angles from the artery in the plane perpendicular to its axis. Ensemble average images were constructed; the absolute velocity and direction were calculated by compounding the left and right averaged images. Simple directional, non-directional velocity and vector maps were constructed.

Flow patterns were sampled in 11 healthy male volunteers at four points of the pulse cycle; peak systole, systolic downswing, diastolic reverse flow and diastolic forward flow and at three sites; the right common and distal superficial femoral and the left common femoral arteries. Stable rotational flow was observed in all subjects, the direction of rotation varying between sides and individuals.

There are theoretical advantages to spiral laminar blood flow; the forward-directed, rotationally induced stability and reduction of laterally directed forces may reduce turbulence in the tapering branching arterial tree and at stenoses and have a beneficial effect on mechanisms of endothelial damage and repair.

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## 9. Helical and retrograde secondary flow patterns in the aortic arch studied by three-directional magnetic resonance velocity mapping

CIRCULATION. 1993 NOV;88(5 PT 1):2235-47. KILNER PJ, YANG GZ, MOHIADDIN RH, FIRMIN DN, LONGMORE DB.

### Background

Helical and retrograde secondary flows have been recorded in the aorta, but their origins and movements in relation to the arch have not been clarified. We set out to do this using magnetic resonance velocity mapping.

### Methods & Results

Three-directional phase contrast cine magnetic resonance velocity mapping was used to map multidirectional flow velocities in the aortas of 10 healthy volunteers.

Computer processing was used to visualize flow vector patterns in selected planes.

Right-handed helical flows predominated in the upper aortic arch in late systole, being clearly recognizable in 9 of the 10 subjects.

Non-axial components of velocity in this region reached 0.29 m/s (+/- 0.05 m/s) as axial velocities declined from a peak of 1.0 m/s (+/- 0.1 m/s).

Helical flow patterns in the upper descending aorta varied between subjects, apparently depending on arch curvature. End-systolic retrograde flow originated from regions of blood with low momentum, usually along inner wall curvatures.

Flow studies in a curved tubular phantom showed right-handed helical flow in the upper "arch" when the inflow section was positioned to simulate ascending aortic curvature, and retrograde flow occurred along the inner wall at end systole during pulsatile flow.

### Conclusion

Helical and retrograde streams are consistent features of intra-aortic flow in healthy subjects that result, at least in part, from the curvature of the arch and the pulsatility of flow in it. They may have significance in relation to circulatory dynamics and the pathogenesis of atheroma in the arch.

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## 10. Spiral laminar flow in arteries?

LANCET. 1991 NOV 30;338(8779):1360-1. STONEBRIDGE PA, BROPHY CM. VASCULAR SURGERY UNIT, ROYAL INFIRMARY, EDINBURGH, UK.

Spiral blood-flow patterns in infrainguinal blood-vessels were observed at angioscopy in 54 patients who underwent peripheral vascular reconstruction; the endoluminal surface had spiral folds in 51 of 75 arteries examined.

Spiral flow patterns, congruous with inherent endoluminal anatomical features, might more accurately represent blood-flow in infrainguinal arteries than current models of laminar flow.

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