An *In Vivo* Model for Studying the Local Haemodynamics of End-to-Side Anastomoses


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**Objectives:** To develop an *in-vivo* model to study the anastomotic flow patterns.

**Design:** Prospective, open, animal study.

**Methods:** Polyurethane grafts with an internal diameter equal to the abdominal aorta (8 mm) of 90 kg pigs were implanted as bypass grafts from the supra-renal to the infra-renal level. A novel technique for constructing anastomoses with different anastomosis angles and only slight dilatation was used. The proximal outflow segment was occluded and the flow rate through the graft controlled by clamping the iliac arteries. Visualisation of the flow-fields at the distal end-to-side anastomosis was achieved by a comprehensive colour Doppler mapping protocol.

**Results:** The angulation of the anastomoses was controllable and reproducible. Gross haemodynamic parameters were stable within physiological ranges and were typical for peripheral bypass grafts. The flow fields at the distal end-to-side anastomosis were visualised and found to be in accordance with those reported by *in vitro* studies. Using different angles of Doppler insonation the same flow field characteristics were found.

**Conclusions:** The model is an appropriate tool for studies of the effects of anastomotic geometry on local flow fields in vivo.

**Key Words:** Vascular anastomosis; Model; *In vivo*; Pigs; Angle; Blood velocity; Colour Doppler ultrasound.

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**Introduction**

The long term patency of implanted vascular grafts is a major concern of every vascular and cardiac surgeon. Development of neointimal hyperplasia within the graft or at the anastomoses are thought to be responsible for the late graft failures.1-6 Because of the localised distribution of neointimal hyperplasia at the anastomoses, local haemodynamics, especially low7-9 and oscillating7,9 shear stresses, are considered to be important factors in this process.2-5

One question is whether the angle of take-off for femoro-femoral cross-over grafts, axillo-femoral bypass grafts, and the distal popliteal anastomoses do influence the local flow fields *in vivo*, and whether this will influence the development of neointimal hyperplasia at the anastomotic sites. *In vitro* studies have, indeed, been conducted to investigate the effect of the anastomotic angle,7-12 but the difficulty in simulation and the complexity of the interactions of the physiological flow waveforms, the non-linear viscous properties of blood, the mechanical properties of the vessel wall, and a clinically relevant anastomosis geometry, diminish the value of *in vitro* studies. Very few *in vivo* studies of local haemodynamics in relation to anastomosis geometry have been conducted,13-15 and no studies have been reported on the relationship between geometry of the distal end-to-side anastomosis and local flow fields *in vivo*. For these reasons the present study was undertaken to develop an animal model which could provide the opportunity to study the relationship between selected geometries of standardised and optimised distal end-to-side anastomoses, and local flow fields *in vivo*.

**Material and Methods**

**Animal Model**

The experiments were performed on pigs (mixed...
Danish Land-race and Yorkshire) with a body weight of 90 kg. The care and use of the laboratory animals complied with the Danish law. After the experiments, the pigs were killed by intravenous injection of saturated KCl during continued anaesthesia. The animals were premedicated with an intramuscular injection of azeprone (Sedaparone® vet), 4 mg/kg, and midazolam (Dormicum®), 500 µg/kg. Methomidat (Hypnodil® vet), 2.5 mg/kg, was injected in an ear vein before endotracheal intubation. Anaesthesia was maintained by Halothane®, 0.5%, and nitrous oxide, 55%, given through a volume regulated ventilator (Engström type ER 311, LKB Medical AB, Sweden), supplemented by continuous intravenous infusion of fentanyl (Haldid®), 1 mg/h, and midazolam (Dormicum®), 23 mg/h. Isotonic sodium chloride, 1.5 l/h, to replace fluid loss and plasma expander (Haemaccel®), 35 ml/g/ml, 0.5–1.5 l to replace lymph loss due to retroperitoneal dissection, were infused throughout the experiment to maintain central venous pressure at a constant level. Arterial and central venous pressures were measured through liquid filled catheters placed in the left carotid artery and external jugular vein. The pressure transducers were connected to a Sirecust monitor (961, UB Med Erlangen, Germany) for continuous monitoring. A surface ECG was recorded on the same monitor. Arterial pO₂, pCO₂, pH, oxygen saturation and haemoglobin were measured repeatedly using a Radiometer ABL 300 (Copenhagen, Denmark). The animals were heparinised by an intravenous bolus injection of heparin (Leo®), 40,000 IU. The activated clotting time (ACT) was measured intermittently using a Haemachrome-meter (Haemachrome System, International Technidyne Corporation) and kept above 400 seconds by further injection of heparin, if necessary.

The abdominal aorta and the iliac arteries were exposed via a mid-line laparotomy and retroperitoneal dissection. All arterial branches between the superior mesenteric artery and the trifurcation were ligated. A left nephrectomy was done, and the right kidney was perfused by a polytetrafluoroethylene shunt from the abdominal aorta just proximal to the superior mesenteric artery (Fig. 1). An electrostatically-spun polyurethane graft with an internal diameter of 8 mm and a wall thickness of 1.5 mm was implanted so that the toe of the proximal anastomosis was positioned 3 cm distal to the origin of the superior mesenteric artery at the abdominal aorta, and the toe of the distal anastomosis was located 13 cm distally. The proximal outflow segment was occluded one aortic diameter proximal to the heel of the distal anastomosis, and the flow rate through the graft was controlled by partial cross clamping of the external iliac arteries 10 vessel diameters downstream of the distal anastomosis (Fig. 1).

The graft was cut according to the shape shown in Fig. 2 (solid lines). The arteriotomy was made using a vascular puncher with a diameter of 8 mm at the toe of the anastomosis, and the punched arteriotomy extended to the heel of the anastomosis (solid lines). The angulation of the anastomoses in the anterior-posterior plane was varied by varying the “toe - heel” length (dotted line) of the graft and the arteriotomy. In all anastomoses studied, the bypass length, defined as the length between the toe of the proximal and the toe of the distal anastomosis was kept constant, but the graft length was different for the different angles of anastomosis. Three distal anastomosis angles were studied: 15° (proximal anastomosis angle = 45°), 45° (proximal anastomosis angle = 45°), and 90° (proximal anastomosis angle = 90°).

![Fig. 1. Schematic drawing of the animal model (all branches of the abdominal aorta between the superior mesenteric artery and the trifurcation ligated). SMA = superior mesenteric artery, POS = proximal outflow segment, DOS = distal outflow segment, PA = proximal anastomosis, DA = distal anastomosis, M = transit time flow probe for blood flow measurements. Black diamonds indicate site of total aortic occlusion. The graft flow was adjusted by reversible clamping of the iliac arteries.](image-url)
Measurements

After anaesthetic and surgical procedures which lasted approximately 6 hours, a pig-tail catheter was introduced into the abdominal aorta and contrast arteriography performed and recorded on video for measurements of the intraoperative dimensions of the bypass graft, the diameters of the abdominal aorta at the heel, at the middle and at the toe of the anastomosis. The anastomosis angle, defined as the angle between the genuine vessel wall and the graft within one vessel diameter of the anastomosis, was studied by means of a 7.5 MHz ultrasound Doppler transducer operated by a Vingmed CFM 750 ultrasonic scanner (Horten, Norway). To visualise the anastomoses three dimensionally, a cast of the abdominal aorta and bypass graft was made post-mortem by injecting a quick curing compound (Acrifix®, Röhn GmbH, Chemische Fabrik, Germany) through an aortic cannula inserted proximal to the superior mesenteric artery. To ensure that the dimensions of the post-mortem casts, i.e. the diameters of the abdominal aorta and the by-pass graft were the same as perioperatively, sutures were tied around the abdominal aorta at several locations prior to sacrificing the pig.

Volume flow was measured using a transit time flow-meter (T208, Transonic Systems Inc. New York, U.S.A.) and a perivascular flow transducer placed between the proximal anastomosis and the superior mesenteric artery (Fig. 1). The flow rate was read from the digital display on the flow-meter. The Reynolds number \( R_e_{\text{mean}} \) and Womersley’s parameter, were calculated from the flow rate, the heart rate, the internal diameter of the graft, and the kinematic viscosity. \[ R_e_{\text{mean}} = \frac{Q_{\text{mean}} \times 2}{\pi \times r_{\text{int}} \times v} \] and \[ \text{Womersley's parameter} = r_{\text{int}} \times \sqrt{2} \times \pi \times f \times \frac{1}{\nu} \] \( Q_{\text{mean}} \) = mean flow rate, \( r_{\text{int}} \) = the internal radius of the graft, \( v \) = the kinematic viscosity, \( f \) = heart rate in Hz.

For evaluation of the flow fields at and downstream of the distal end-to-side anastomosis, the 7.5 MHz ultrasound Doppler transducer (Doppler frequency = 6 MHz) was fixed externally at two predetermined angles (typically 60 and 120 degrees) in relation to the longitudinal axis of the abdominal aorta. Sector scannings in the anterior-posterior plane along the flow axis, in the centre of the anastomosis, were made at different axial positions, at the heel, the toe and one diameter downstream of the toe (1DDD), by moving the transducer position (Fig. 3D). By rotating the fixed transducer in every measurement position by 90°, a sector scan (left-right plane) perpendicular to the anterior-posterior sector was made in the same measurement positions (Fig. 3C). Using

GEOMETRY AND ANGLE OF ANASTOMOSIS.

Fig. 2. Geometry and angle of the anastomoses. Top row: The graft was cut from toe via a half circle and extended to the heel (solid line). The arteriotomy was made by a vascular puncher with a diameter equal to that of the genuine vessel and extended to the heel (solid line). In this way the anastomosis was made without dilatation in the left-right plane. In the anterior-posterior plane the angulation was varied by varying the length toe - heel (dotted line). Bottom row: The photograph on the left shows a, postmortem, acrylic cast of the distal anastomosis (pig EC13). The occlusion was removed when making the cast. To the right - a perioperative 2D-echo (B-mode image) of the same anastomosis.
Table 1. Anatomical dimensions

<table>
<thead>
<tr>
<th>No. of pigs</th>
<th>Aimed angle degrees</th>
<th>Observed angle degrees</th>
<th>Relative diameters</th>
<th>Graft length cm</th>
<th>Bypass length cm</th>
<th>Anastomosis length cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
<td>14.3 ± 1.3</td>
<td>1.2 ± 0.2</td>
<td>1.5 ± 0.2</td>
<td>1.2 ± 0.1</td>
<td>13.5</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>44.5 ± 3.9</td>
<td>1.1 ± 0.1</td>
<td>1.2 ± 0.1</td>
<td>1.2 ± 0.1</td>
<td>14.5</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>83.5 ± 3.5</td>
<td>1.0 ± 0.2</td>
<td>1.0 ± 0.1</td>
<td>1.0 ± 0.2</td>
<td>23.0</td>
</tr>
</tbody>
</table>

Aimed angle = intended angle of the distal anastomosis. The actual angle (observed angle) was measured by intra-operative 2D-echo. Toe, Middle and Heel are the diameters of the abdominal aorta at the distal anastomosis divided by the measured graft diameter, measured from intra-operative angiography.

Table 2. Haemodynamic parameters

<table>
<thead>
<tr>
<th>No. of pigs</th>
<th>Angle Degrees</th>
<th>Re_{mean}</th>
<th>α</th>
<th>Flow 1/min²</th>
<th>HR beats · min⁻¹</th>
<th>AP_{mean} mm Hg</th>
<th>CVP mm H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>15</td>
<td>404 ± 67</td>
<td>6.0 ± 0.8</td>
<td>0.58 ± 0.09</td>
<td>76 ± 20</td>
<td>61 ± 11</td>
<td>5 ± 1</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>442 ± 44</td>
<td>6.0 ± 0.8</td>
<td>0.63 ± 0.06</td>
<td>77 ± 14</td>
<td>64 ± 13</td>
<td>5 ± 4</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>449 ± 42</td>
<td>5.6 ± 1.2</td>
<td>0.64 ± 0.06</td>
<td>69 ± 26</td>
<td>68 ± 14</td>
<td>4 ± 2</td>
</tr>
</tbody>
</table>

AP_{mean} = mean arterial pressure, HR = heart rate, CVP = central venous pressure, \( \text{Re}_{\text{mean}} \) = mean Reynolds number in the graft calculated from the formula: \( \text{Re}_{\text{mean}} = \frac{Q \times 2}{\rho \times \text{f}_\text{avg} \times \text{D}_\text{ref}} \), where \( \rho \) = the kinematic viscosity (≈ 0.038 stokes) and \( \text{f}_\text{avg} \) = the internal radius of the graft. \( \alpha \) = Womersley’s parameter = \( \text{r}_\text{int} \times \sqrt{2 \times \pi \times f \times \text{D}_\text{ref}} \), where \( f \) is the heart rate in Hz.

dedicated software (Echo-Disp, Vingmed, Norway), digital velocity data from every pixel in the colour Doppler image during one heart cycle was downloaded from the ultrasound scanner to a Macintosh computer. Using the same software a dynamic visualisation of the flow fields in each measurement position was made to allow off-line comparison. The beam width of the transducer used in this study was measured in vitro using a commercially available moving string tester (Doppler phantom, type DP1, BSS Medical Electronic AB, Sweden) and found to be 1.9 mm in the range 2–5 cm.

**Results**

To develop this model a total of 36 pigs were used. Twelve pigs were used for pilot studies to establish the surgical technique, develop an optimal anastomosis geometry, and to determine the graft diameter and length required for the different angles of anastomosis without kinking or distorting the graft.

Out of the 24 remaining pigs we have chosen to present 10: four pigs with a distal anastomosis angulation of 15°, three with one of 45°, and three with one of 90°. The criteria for inclusion were haemodynamic parameters comparable to peripheral bypasses (\( \text{Re}_{\text{mean}} \) and Womersley’s parameter), stable gross haemodynamics during all measurements, and successfully recorded anatomical data of the anastomosis geometry. The reasons for excluding 14 out of the 24 pigs were inadequate stability and haemodynamic parameters outside the clinical range (seven initial studies), death of the pig before the end of the entire measurement series (six pigs), and one pig was used to study the influence of a stenosis in the proximal outflow segment.

The anatomical data of the distal end-to-side anastomosis are presented in Table 1. The fifteen degree anastomosis had a slight tendency for dilation at the middle, but no dilatation was identified with less obtuse angulation. Fig. 2, bottom row, illustrates an example of the post- and intraoperative assessment of the anastomosis angle in the anterior-posterior plane (pig EC13, distal anastomosis angle = 45°). The geometry of the toe was smooth which was also the case for the other angles of anastomosis.

The gross haemodynamic parameters are listed in Table 2. All values were measured during colour Doppler measurements, i.e. during the last 2 to 3 hours of a study day which typically lasted 10 to 11 hours. Gross haemodynamics were stable at all measurement positions from start to end of these measurements. In Fig. 4, \( \text{Re}_{\text{mean}} \) and Womersley’s parameter are presented for the three groups.

In Figs 5 and 6, examples of the colour Doppler measurements are presented, applied to a 45 degree anastomosis (pig EC13). Figure 5, top row, depicts the
anterior-posterior plane at the centre of the anastomosis, 60° insonation. In the peak flow and early deceleration phases the velocities are very high at the toe of the anastomosis. During deceleration the lowest velocities are seen at and just downstream of the toe. Figure 5 bottom row illustrates the same anastomosis, 125° insonation. At the toe reversed velocities fluctuating in deceleration. At the floor of the anastomosis, another zone with low or reversed velocities towards the heel during the entire heart cycle. Viewed in the left-right plane, Fig. 6, top row, the low velocities are most apparent to the right at the toe, and during deceleration even reversed velocities occur at the toe. In Fig. 6, bottom row, the same anastomosis, 125° insonation, low velocities are demonstrated to the right at the toe. Combining the information in Figs 5 and 6, a fluctuating zone with low and reversed velocities is seen at the toe of a 45° anastomosis in early and late deceleration. At the floor towards the heel of the anastomosis, low and retrograde velocities, most pronounced during deceleration, indicate flow disturbances.

Discussion

A precondition for a study of local haemodynamics at vascular anastomoses is stable haemodynamics within each pig, comparable haemodynamics between the different groups, and local flow fields comparable to the clinical situation. From the literature, clinically relevant \( R_{\text{mean}} \) and Womersley's parameters, i.e., relevant for the study of peripheral and coronary arteries, should range between 110–900 and 1.9–7.2, respectively. In this study the \( R_{\text{mean}} \) and the Womersley's parameter ranged between 297–576 (mean = 424 ± s.d. = 57) and 4.0–7.1 (mean = 5.9 ± s.d. = 0.8) for all pigs, which was accomplished by careful anaesthesia and reversible cross-clamping of the iliac arteries without changing the shape of the flow waveforms or introducing significant effects on the stability of the gross haemodynamic parameters. The model proved to be very stable during the measurements.

From previous in vitro fluid dynamic studies it is known that several parameters influence the flow fields: The angulation of the distal end-to-side anastomosis; the ratio of the cross-sectional area of the host vessel to that of the graft; a dilatation of the anastomosis; the curvature of the by-pass graft and of the by-passed vessel; the rate of flow; the pulsatility of flow; and the shape of the pulsatile flow waveform. In addition the degree and location of a stenosis in the proximal outflow segment

![Fig. 3. Principle of the ultrasound Doppler measurements.](image)
should be considered, but conventional knowledge about haemodynamics at stenoses\textsuperscript{27-29} may not be appropriate, since part of the flow is shunted past the stenosis.

The anastomotic angle is a geometric parameter of major importance which can be varied in the clinical setting. \textit{In vitro} studies have shown that varying the angulation causes different patterns of flow separation zones and vortex formation at the heel, toe and floor of the distal end-to-side anastomosis.\textsuperscript{7-10,12} These flow patterns are believed to be associated with development of neointimal hyperplasia at vascular anastomoses. In fact, neointimal hyperplasia at the distal end-to-side anastomosis has been found to initiate in these regions of the anastomoses.\textsuperscript{4,5} The present model was therefore developed to gain an understanding of the influence of reconstructive surgery on the local haemodynamics at vascular anastomoses \textit{in vivo}, realising that only by systematically evaluating the influence of the different variables separately, keeping the other variables constant, can any conclusion be drawn as to which should be controlled most carefully in the clinical setting.

A long straight vessel without any branches was made by ligation of all arterial branches from the abdominal aorta between the superior mesenteric artery and the trifurcation. The left nephrectomy was done to get room for the Doppler transducer, and facilitate the access to the vessels at the posterior wall of the abdominal aorta in that region. The right kidney was perfused by an aorto-renal shunt, since we had ascertained during the pilot studies that it was not possible to keep the pig stable during the measurement period without at least a partially functioning kidney. The reason for these procedures and for the occlusion of the proximal outflow segment was the wish to standardise the model, to facilitate flow rate measurements — in this way the flow rate through the graft could be measured in one position only —
and to study one variable only. For the same reasons the described surgical technique for making anastomoses was developed and carefully chosen. Using this technique, the anastomosis angle was found highly reproducible in the \textit{in vivo} situation, and the dilatation of the anastomoses was minimised. In order to standardise the model, the toe of the distal and the proximal anastomosis were positioned in the same location in all pigs, and the length of the bypass graft as well as the bypass length were constant, but the curvature of the bypass graft varied according with the different anastomosis angles. This curvature would be expected to influence the velocity profiles within the graft at the entrance of the anastomosis, and the flow fields of the distal end-to-side anastomosis. Consequently, it is necessary to present anatomical results as lengths of anastomoses/arteriotomies, grafts, and bypass lengths, and to measure the velocity profile just before the blood enters the anastomosis to fully describe the inlet anastomotic conditions created by the curvature of the graft.

From \textit{in vitro} studies a complicated three dimensional structure of the flow field would be expected at the distal end-to-side anastomosis. To get a reliable impression of the overall flow field characteristics, we used colour Doppler, accepting that the velocity measurements were semi-quantitative. Using this measuring technique the entire velocity field may be measured within one heart beat, although, only one velocity vector, the one along the colour Doppler sector, is measured. As for other \textit{in vivo} techniques for point velocity determinations, the limited spatial resolution made the large vessel size an important aspect of the model. For colour Doppler systems operated in colour Doppler sector mode the spatial resolution depends on the beam width (in this study approximately 2 mm) of the transducer, the sector angle chosen (in this study typically 20° and 30°), the number of sector lines across the sector angle (this colour Doppler system: 32 for a sector angle of 20° and 64 for one of 30°) and the number of gates along the individual sector line (number of gates along a sector line for this colour Doppler system = 128). The temporal resolution depends on the frame rate of the Doppler system (for this colour Doppler system: up to 55 frames/second, typically 20-40 frames/second).
Fig. 6. Colour Doppler measurements at the toe of the distal anastomosis in the left-right plane, (pig EC13); the transducer is rotated by 90° compared with the measurements in Fig.5. Doppler probe angle = 60° in the top row and 125° in the bottom row. Colour coding as in Fig.5. In peak flow the highest velocities are seen towards the left. Starting in early deceleration reversed velocities (red) are seen a little to the right of the toe. Bottom row - the same anastomosis with a Doppler probe angle = 125°. In peak flow, the highest velocities to the left. A low velocity zone (dark red/black) starting in early deceleration is seen to the right at the toe. At the floor, low velocities (dark red/black) starting in middle to late deceleration, but no zones with reversed flow are seen.

and on the heart rate. The flow visualisation was optimised by insonating the flow fields from two different transducer angles, enabling a comparison of the same flow field at the anastomosis near wall. The principle is shown in Fig. 7 for an idealised 45° anastomosis with idealised streamlines and vortices at the heel and toe. The six Doppler sectors enable a thorough evaluation of the flow field at the anastomosis as well as at the entrance of the anastomosis. At the anastomosis near the wall the colour Doppler sectors with different angles of insonation are evaluating the same location and thus verify the flow patterns, i.e., at the toe the sectors with different insonation angles should show the same velocity patterns at the anastomosis near wall. At the floor of the anastomosis the information would be supplementary. This approach diminishes the angle ambiguity present when using ultrasound Doppler in evaluating flow fields that are basically 3-dimensional. In order to disclose small regions of disturbed flow, the exact positioning of the colour Doppler sector is very important. Figure 8 shows an example in which the zones of reversed flow at the toe and at the floor towards the heel of the anastomosis are not seen in the left-right plane while present in the anterior-posterior plane. In the anterior-posterior plane the same problem was encountered. When even a slight skewness of the anastomosis in the left-right plane was present, the low velocities were measured at the walls of the anastomosis in the left-right plane (Fig. 6), and thus out of the central anterior-posterior plane (Fig. 5, top row). The presence of these fluctuating flow fields with a limited spatial extension emphasises the need for a comprehensive measuring protocol, and highlights the importance of a thorough evaluation of the flow fields in future studies. The disclosure of flow disturbances at the distal end-to-side anastomosis is in accordance with those reported in earlier in vitro studies. 7-12 Furthermore, the flow disturbances are measured at locations where neointimal hyperplasia seems to initiate. 3-5

The perspectives of the present model are four-fold. 1) Due to the controllability of the different variables mentioned, this model can provide basic knowledge of the overall flow field characteristics at vascular end-to-side anastomoses perioperatively;
knowledge that may be valuable when planning studies in the clinical setting. 2) For the same reasons, quantitative methods, i.e., high frequency pulsed Doppler ultrasound and MR may be applied. 3) It is also suited for in vitro comparison, since post-mortem casts of the peri-operative anatomy are made which can be used for making replicas of the anatomy for in vitro studies. 4) Finally, the pig model, could be used for chronic experiments to study the development of neointimal hyperplasia at vascular anastomoses as a function of local haemodynamics.

In conclusion, we have developed an animal model for acute haemodynamic studies in which, using a novel anastomosis technique, the angulation of the distal end-to-side anastomosis may be varied and reproduced with only slight dilatation, and the flow rate is adjustable within clinically relevant values under stable gross haemodynamic conditions. Using ultrasound colour Doppler technique disturbed flow within small confined areas towards the walls of the anastomoses may be visualised and verified using a different angle of insonation. These results highlight the importance of a comprehensive measuring protocol in future studies, and seems to verify the in vivo existence of flow disturbances at the distal end-to-side anastomosis reported by in vitro studies.

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References


Fig. 8. Importance of Doppler sector position. To the left a Doppler sector in the anterior-posterior plane. The white line illustrates the centre of the Doppler sector at the toe of a 45° distal anastomosis. Note reversed flow (blue) at the toe and at the floor towards the heel of the anastomosis (pig EC13). Colour coding: red towards, blue away from the transducer (positioned at the top of the image). To the right the same anastomosis in the left-right plane, at the same time in the heart cycle. The plane is perpendicular to the white line in the other illustration. Due to the position of this plane only low velocities (dark red/black) are seen at the toe.


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