Part X

Factors influencing results

Intraoperative Determinants of Infrainguinal Bypass Graft Patency

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Between 5 and 30% of infrainguinal reconstructions occlude within 30 days of the original operation and the one-year failure rate may be as high as 50% (1, 2, 3, 4, 5, 6, 7). There are a number of reasons for early occlusions, which you may simply classify as technical problems (operator-dependent), graft-dependent reasons or a compromized runoff (an intention to do the operation with a too optimistic view despite unlucky circumstances). Among causes, on which we are able to influence, is the choice of graft and its condition as well as the technical result of the operation and the hemodynamics of the patient for the moment being. Technical errors have been the reason for early occlusions in 38-55% (5, 8). Unrecognized technical errors are thus of great importance and the less experience the surgeon has, the more important it is to have a method to detect these errors and to correct them. It is not possible to pinpoint the method of choice to detect the errors. It may be angiography, angioscopy or Duplex ultrasound, but you should have a method with which you are familiar and which is useful. In the end it should thus be possible to have a morphologically well functioning graft. Graft associated failures are common and is also operator-dependent since it is the operator who chooses which graft he is going to use, an important predictor of outcome (9).

But there are of course causes which we are unable to change directly i.e. the outflow conditions which have usually been evaluated preoperatively since this is a prerequisite for the operation. Finally unspecified causes may be found in 15% (8).

Furthermore it is intraoperatively possible to measure flow as well as pressure in the operative field and by doing this get at prognostic evaluation from the available facts concerning the reconstruction.

Detection of faults

Most vascular surgeons agree that some form of completion control is necessary to minimize the number of technical defects during femoro-popliteal and -distal by pass grafting. The aim is to reduce the number of early graft failures. There are numerous methods available to control a procedure's quality, a fact that may reflect that none is ideal and able to cover both the proximal and distal anastomosis as well as the entire graft.

In many institutions a completion arteriography is performed in every patient undergoing an infrainguinal bypass. This has been the standard strategy for decades (10, 11), but more recent methods such as Duplex-scanning and especially angioscopy is growing in popularity. The reason why arteriography remains favourite in many institutions may be that it is a well-established and adequate method for visualizing the graft, the distal anastomosis and the outflow vessels (12). Vascular surgeons generally are also comfortable in performing and interpreting angiograms.

The minimalistic approach to completion control is palpation of pulses in the outflow vessel and in the graft. This is usually combined with insonation of the same areas with continuous wave Doppler. When these simple tests indicate a problem, arteriography is performed for verification and localization.

Blankenstein et al 1995 studied 54 infrainguinal by passes to evaluate the efficacy of this approach. Pulse palpation and Doppler insonation were compared to intraoperative pulse volume recording and measurements of volume blood flow in the graft, using transite time ultra sound. They classified the pulse palpation test as positive (indicating a technical fault) when pulses were absent and the Doppler insonation test when flow velocities in the outflow artery not improved after the by pass was complete. When these tests were positive it was highly indicative for the presence of a technical fault. The relative risk was 14.7 for a positive pulse palpation test and 12.3 for Doppler insonation. Interestingly, the positive test chosen for volume blood flow (a flow <50 ml/min) didn't detect technical problems or early failure, but was closely related to outflow resistance (13).

Among authors that have found Duplex-scanning a valuable tool for completion control, many emphazise the need for an expert performing the scan in order to reach acceptable results (14, 15). Other authors have not found evidence to support the use of Duplex scanning to identify technical problems and grafts at high risk for early postoperative failure (16, 17). In one of these, a prospective blinded study, 20 infrainguinal reconstructions with insitu vein grafts were used to compare the efficacy of arteriography, angioscopy and Duplex-scanning (16). Angioscopy and arteriography

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TABLE I
Methods of measuring intraoperative determinants for infrainguinal bypass graft patency

Flowmeasurements	Measurements of the resistance
Resting flow Augmented flow (after Papaverine injection)	Total peripheral resistance Impedance of the conduit (the resistance to flow in the graft proper) Quantification of the effective diameter of the graft

were found to be more sensitive than Duplex-scanning to detect graft side branches that still were patent. Angioscopy was also superior to both the others techniques in identifying incompletely cut valve cusps. Besides inferiority in these two areas, Duplex scanning also had problems with the distal anastomosis. It was impossible to evaluate in three patients, and in the remaining the false positive rate for a significant stenosis was 10 % (16).

Endoscopy is possibly the main competitor for being the standard completion control technique and many studies have compared angioscopy to arteriography (18, 19, 20). For example Miller et al studied infrainguinal by pass grafts and randomized the completion control to either angioscopy or arteriography. Even though their study did not reach statistical significance of an improved early failure rate for angioscopy patients over those evaluated with arteriography, there was a tendency in favour of angioscopy. Other authors with similar study set up have proven angioscopy superior for identifying valve remnant problems, but not for evaluation of the distal anastomosis (20, 21). An issue not studied in these, and most other investigations, is to what extent valve remnants effect early outcome.

In summary: completion control is necessary to minimize early failures. Arteriography is the standard method and has the advantage of making it possible to assess the outflow tract. Selective arteriography based on pulse palpation and Doppler insonation findings is an alternative routine to screen for problems when completing a by pass. Angioscopy is likely to be the best method to evaluate the efficiency of valve destruction, while Duplex scanning as the sole method for completion control probably should be reserved for centra with special interest in this technique. Moreover, the type of procedure should also influence what strategy finally is chosen. Angioscopy is preferred when an in situ vein by pass is performed and arteriography for reversed veins and procedures with a questionable outflow vessel. In som circumstances a combination of both is needed. Ultimately it is the vascular surgeon's experience and preferences that are the main determinants of which method that is utilized.

Prediction of failure, the quality of the reconstruction

Now is the time to look at the functional parameters of the graft. Intraoperatively these comprise of flow measurements and measurements of the resistance of the outflow as well as the impedance of the conduit (the resistance to flow in the graft proper) and recently also quantification of the effective diameter of the graft. The importance of these parameters are under debate and much has been done in order to find the golden solution. In many cases the correlations with the long term patency is fairly weak. It is thus not as yet possible to give a totally clearcut answer to the question if the bypass under construction really is worth while. If we could find some critical values in the intraoperatively measured functional parameters different options would be open for us. Bypasses identified with increased risks of early failure could possibly be saved e.g. by pharmacotherapy (22, 23, 24, 25), by measures undertaken to lower a high peripheral resistance e.g. a sequential bypass (26, 27) or by the construction of an AV-fistula (28, 29).

The ultimate goal would be to use the haemodynamic measurements at operation to identify a group of patients in whom bypass is likely to fail or where the parameters are so good that it might be possible to discontinue or skip further surveillance. And last but not least, futile attempts of re-reconstruction could be avoided and time, money and morbidity could be saved and mortality lowered. In the long run there is of course the hope that we should be able to noninvasively measure the peripheral resistance before the operation and thus avoid unnecessary interventions(30). The purpose of the following paragraphs is to introduce the reader to flow and resistance measurements and their meaning in infrainguinal bypasses.

The flow measurements

Although haemodynamic parameters in grafts have been measured already since the mid sixties (31, 32, 33, 34, 35, 36) little has been incorporated in the clinical everyday work since the results have been partly inconsistent. Most of the older reports had made use of the electromagnetic flowmeter already described in 1936 (37). Clinically introduced during the early 1960´s the method has been abandoned due to a number of sources of error and the notorious difficulties with calibration. Errors in excess of 50% have been recorded during clinical measurements (38).

The Doppler flowmeter has been used widely to measure volume flow but the accuracy here is dependent on determination of vessel cross-sectional area which varies with changes in flow profiles of pulsatile flow (39). But even with modifications designed to eliminate the problems a low accuracy and reproducibility has been found (40).However, more recent experience has given more reliable results mostly due to more reliable instrumentation.

Thus the transit-time flowmeter, described already in 1962 (41) was brought into clinical practice in the early 1980´s (42). A contralaterally placed metal reflector reflects ultrasound from one upstream transducer and one downstream tranducer and the difference in the upstream and downstream transit-time is proportional to the volume flow. The devise has turned out to be highly accurate in validation studies and the reproducibility is good (43, 44). It needs no calibration before measurements, it is not sensitive to changes in hematocrit nor is it dependent on vessel diameter or wall thickness estimation.

Flow measurements in the graft may be perfomed without and with augmentation(papaverine) of the flow in the graft. It is of utmost importance that the patient is haemodynamically stabilized before any measurements are performed (45). Flow measurements have been used to test the integrity of the bypass as well as the outflow resistance.

Results reached with the transit time flowmeter seem interesting. Although technical errors of the bypass cannot be assessed clearly with flow measurements only (13) it has been fairly easy to detect unligated branches in situ bypasses. Thus Lundell & Bergqvist (46) in a study concerning femoropopliteal and femordistal bypasses were able to show that a difference in flow of more than 25ml/min between the proximal and distal part of the graft regularly indicated not ligated AV-fistulas or a retained valve cusp. Among femorodistal, but not among femoropoliteal bypasses, they found a significantly higher flow measured during the operation (mean 107 ml/min) in bypasses open after 90 days versus those who had occluded (mean 45 ml/min).

Albäck (47) also using the transit time flowmeter, found that a low graft flow was associated with a poor outcome.Graft flow and maximum flow capacity measurements were significant for all grafts together and for crural bypasses,but not for bypasses with pedal outflow. Femorocrural grafts with a flow below 53 ml/min had a 1-year patency rate of 22% and grafts with higher flow values had a patency of 63%. The maximum flow capacity was better in identifying a subgroup of crural reconstructions with a superior patency rate and thus bypasses with a maximum flow capacity (i.e. after injection of 40mg Papaverine into the graft) of over 110ml/min had a 1-year assisted primary patency of 76% whereas only 24% of those bypasses with lower values were patent. However, Blankensteijn et al. (13) with a cutoff point of 50 ml/min found a positive predictive value of only 13%.

Intraoperative measurements with transit time flowmeters give a limit around 50-60 ml/min below which the outcome of the bypass is clearly worse than in the event of higher resting flow (Table II).

Generally, infrainguinal veingrafts with high mean flow show higher patency rates. Many investigators have experimentally demonstrated that long-term reduced levels of flow and shear lead to greater amounts of neointimal hyperplasia (48, 49, 50, 51). It has also been possible to decrease the subendothelial proliferation in vein grafts in dogs by creating an AV-fistula (48). It is thus not surprising that intraoperative flow also predicts the development of stenosis in infrainguinal bypasses with vein. In a study by Ihlberg et al. (52) it was evident that grafts with event-free outcomes had a higher graft flow(98ml/min) than grafts that either developed a stenosis (77ml/min) or occluded (68ml/min). The maximum capacity flow was also higher for eventfree

TABLE II
Intraoperative measurements of resting volume graft flow after infrainguinal reconstruction

Author	Distal anastomosis	Cut off	PPV	NPV	Patency
(46)	crural art	60ml/min	63%	85%	
(13)	popl.crur.ped	50ml/mi	13%	91%	
(47)	crural art	53ml/min			<23% / >63%

grafts(158ml/min) than for stenosed or occluded grafts (115 ml/min and 106ml/min). Since there are several experimental studies suggesting that a low flow state and a low shear stress accelerates the formation of myointimal hyperplasia the abovementioned findings are of utmost importance. It seems as if, in the near future, it would be possible to draw clinical consequencies from intraoperative measurements and thus conduct the clinical follow-up on a more effective cost/benefit basis. This of course means that grafts with a bad prognosis should be followed closely yet not abandoned since there are maybe a need of a functioning graft for three months in order to heal an ulcer after which the state of the limb may remain stable at least for some time.

Resistance measurements

Outflow peripheral resistance is the ratio between a pressuregradient over the distal vascular bed and volume flow. It may thus be expressed as the peripheral resistance in mmHg/ml/min (p.r.u.) or in case the graft pressure is divided with the proximal flow walue, as mPRU (peripheral resistance units). All current methods of measuring peripheral resistance must be executed intraoperatively. The measurement is either performed by simultaneously recording the volume flow and the direct pressure. The resistance is determined by measuring the integral of pressure and the volume of fluid injected (53). It may also be measured by recording the pressure established during an infusion of blood at a constant flow rate while a computer calculates the peripheral resistance value from a graph showing the pressure as a function of the volume infused. This is conveniently done by using a catheter with an infusion channel and a pressure tranducer at its distal end (30). Ascer et al (53, 54, 55) in the eighties introduced measurement of the resistance clinically. The results, which in the beginning were stunning, have unfortunately not been consistent in the hands of other investigators and thus the method has not been introduced in the clinical praxis.

A variety of methods of estimation of the resistance including the bypass in the measurements, have been used. Values above which virtually all grafts occlude have been found. Parvin et al (56) after a period of four months follow-up found a critical value of 1200 mP over which the results were significntly worse. No graft with a resistance over 1500 mPRU survived more than 1,5 months. And according to Cooper et al. (57) the best discriminants to separate the values in limbs with a patent graft from those with a thrombosed graft at 30 days postop were 1400 mPRU before papaverine and 800 mPRU after papaverine. In Davies´ et al. study (58) grafts anastomosed to the popliteal artery or the tibioperoneal trunk, that stayed open at 30 days postop, had amean resistance value of 0.40 p.r.u. compared with 0,97 p.r.u. in those that failed. For grafts anastomosed to crural vessels the corresponding values were 0,58 versus 1,09 p.r.u. (Table III). But there is a great deal of overlapping(46, 59, 60). The method has thus not found its place in clinical practice. And fairly recently once more in a large material the method was found to be nonreliable at least as far as making a prognosis of graft failure from the total outflow resistance (61). The problem is that some grafts with distal and diseased outflow may enjoy extended patency.

Thus the method has been open to refinements and Schwartz et al (62) introduced the conduit specific measurement in measuring the longitudinal impedance which gives the resistance of the graft proper. The method is somewhat technically demanding but gives a 90% positive and negative predictive value for primary failure. It uses phase relationships and the relationship

TABLE III
Resistance measurements in infrainguinal bypass surgery
(AK = above knee, BK= below knee, tib-per trunc = tibio-peroneal truncus, mPRU = mmHg x min/ml, p.r.u. = mmHg/ml/min)

Author	Distal anastomosis	Figure predicting failure		Follow-up
		During resting flow	After papaverine	
(26)	AK,BK,crural,pedal	>1,2 p.r.u.		3 months
(56)	BK,crural	>1200 mPRU		4 months
(57)	AK,BK,crural	>1400 mPRU	>800 mPRU	30 d
(58)	AK to crural	>1,55 p.r.u.	>1,02 p.r.u.	30 d
(58)	AK,BK,tib-per trunc	>1238 mPRU	>0,97 p.r.u.	30 d
(58)	single crural	>1222 mPRU	>1,09 p.r.u.	30 d
(46)	crural			90 d
(46)	BK			90 d

of pressure and flow during pulsatile flow. This method seems to be unaffected by changes in peripheral resistance i.e. injecting vasodilators have little effect on the conduit but may change the peripheral resistance significantly. The pressure in the graft is measured both proximally and distally and flow is measured in the region of the proximal graft.

Using software specifically designed for this purpose hemodynamic calculations are performed. Pulsatile flow is used and Fourier transformation of the respective waveforms is used. Using this method it may thus be possible to select those grafts that may be successfully salvaged even after an episode of thrombosis, i.e. you may say that this graft is a very good one.

A sophisticated way of looking at the bypass has been introduced by Schwartze's group (63). This is the variable of ¨effective hemodynamic diameter¨ (EHD) of the graft which quantifies the size of the conduit. It is also independent of outflow (i.e. not affected by papaverine) and highely predictive of patency (after multivariate analysis). The method again uses pressure measurements proximally and distally in the graft as well as flow measurement just distal to the proximal anastomosis. By computing the sampled data, into which the length of the graft is incorporated, the EHD is computed. An EHD of less than 3.6 mm has a positive and negative predictive value of 86% and 88% respectively for secondary graft failure.

In summary: both flow measurements and mesurements of peripheral resistance, the longitudinal impedance and EDH give hints about the possible durability of the bypass. However, no one of the methods is 100% foolproof. Much valuable work has been done in this regard and hopefully in the near future a noninvasive method to estimate the outcome of a planned reconstruction will emerge.

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