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Preliminary Report

Effect of haemodynamic variables on surgically created arteriovenous fistula flow

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Abstract

Background. The immediate success and flow rate of a newly constructed arteriovenous fistula is dependent on several haemodynamic factors affecting the inflow and outflow of the fistula.

Methods. In this study we evaluated the effect of preoperative arterial blood pressure, arterial inflow, subclavian venous flow, and operative venous outflow resistance on the immediate success, with special reference to the quantity of the fistula flow in 32 patients undergoing internal arteriovenous fistula operations. Flow measurements were done by utilizing colour flow duplex imaging and measurement of venous resistance of the fistula vein was accomplished indirectly by a newly developed simple system.

Results. A preoperative subclavian venous flow rate of less than 400 ml/min was associated with higher rate of immediate failures ($P<0.05$) with a negative predictive value of 100% with 100% sensitivity. Regarding immediate failures, no other haemodynamic measurement was found to affect the success of a newly constructed fistula significantly. A linear correlation between the measured haemodynamic values and the quantity of postoperative fistula flow was not found. However, an arterial inflow value of $\geqslant 40$ ml/min was associated with higher fistula flow rates ($P<0.05$).

Conclusions. The immediate success and flow of a newly constructed arteriovenous fistula is mainly dependent on arterial inflow and subclavian venous flow. An arterial inflow rate of 40 ml/min or more and subclavian venous flow rate of 400 ml/min or more measured by colour flow duplex imaging prior to the operation will be associated with better outcomes, and therefore the use of colour flow duplex imaging is warranted during the evaluation of patients who are candidates for an arteriovenous fistula operation.

Key words: arteriovenous fistula; haemodialysis; haemodynamics

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Introduction

A well-functioning arteriovenous fistula (AVF) with a minimum flow rate of 200 ml/min is mandatory for successful maintenance haemodialysis [1–3]. It is known that about 5–15% of all surgically created AVFs fail before maturation [4–7] and these 'immediate' or 'early' failures are generally regarded as technical failures, although several haemodynamic parameters may also play a role. In this study we prospectively investigated the effects of preoperative arterial blood pressure (ABP), arterial inflow (AI), subclavian venous flow (SVF), operative venous outflow (VO) (resistance of fistula vein) on the early outcome and flow rate of a newly constructed AVF. The possible predictive value of the above mentioned outflow and inflow parameters on the success of a surgically created AVF is also investigated. Furthermore, fistula maturation was directly assessed by successive measurements of fistula flow. To date no previous study has addressed these issues.

Subjects and methods

All patients ($n=32$) requiring AVF for maintenance haemodialysis operated between September 1994 and February 1995 were included in this study. Patients with AVF construction using a graft were excluded. History of diabetes and prior subclavian vein catheterization were carefully recorded. All fistulae were done by the same surgeon who had performed more than 100 AVF operations previously. Twenty-seven patients had primary and five patients had secondary AVF operations. Primary fistulae were created at the wrist in an end-to-side fashion using cephalic vein and radial artery. All secondary fistulas were brachiocephalic and created at the antecubital fossa. Fistulae were preferentially created on the side without any prior subclavian vein catheterization history. All fistula operations were performed under local anaesthesia and no anaesthetic substances, artificial respiration, or heparinization were utilized during any of the procedures. Prior to the skin incision, systolic and diastolic blood pressures at the ipsilateral arm were measured by a sphygmomanometer, and mean blood pressures were calculated from these values.

Preoperatively the ipsilateral distal subclavian vein was

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evaluated infraclavicularly by utilizing colour flow duplex imaging (CFDI) (Model SSA 27A; Toshiba, 7.5 MHz probe) for the presence of thrombosis, as reported elsewhere [8], and the subclavian venous flow rate was measured from the flow curves obtained during unforceful inspiration without any special respiratory manoeuvres. Arterial inflow of the artery that would be used in AVF construction was measured preoperatively by CFDI. All duplex flow measurements were performed from standard locations by a single, experienced radiologist on three occasions and the average value of these three measurements was recorded. In order to evaluate the resistance of the venous run-off bed of the ipsilateral arm, we developed a simple system as depicted in Figure 1. The same system (interconnected syringes and tubings) was used in all patients after being gas sterilized. The time required for 50 cc saline to completely flush out through this system when opened to atmospheric pressure was 21 s. For the evaluation of differences of venous outflow resistance in each patient; after the system was filled with a constant volume (50 cc) of saline, the tip of the catheter was inserted 0.5 cm into the vein which would be used for the AVF construction and was lightly ligated by plain catgut. The system was then opened and the time required for the flow of 50 cc saline through the vein was measured. Three measurements were made for each patient and the mean of the second and third measurements was recorded. During the measurements special care was taken to avoid compression of the patient's arm. The first measurement was intentionally omitted because it might be flawed due to possible venous spasm. Higher values in seconds represented increased resistance of venous outflow tract, since the volume of the flushed saline and the hydrostatic pressure of the system was constant during each measurement.

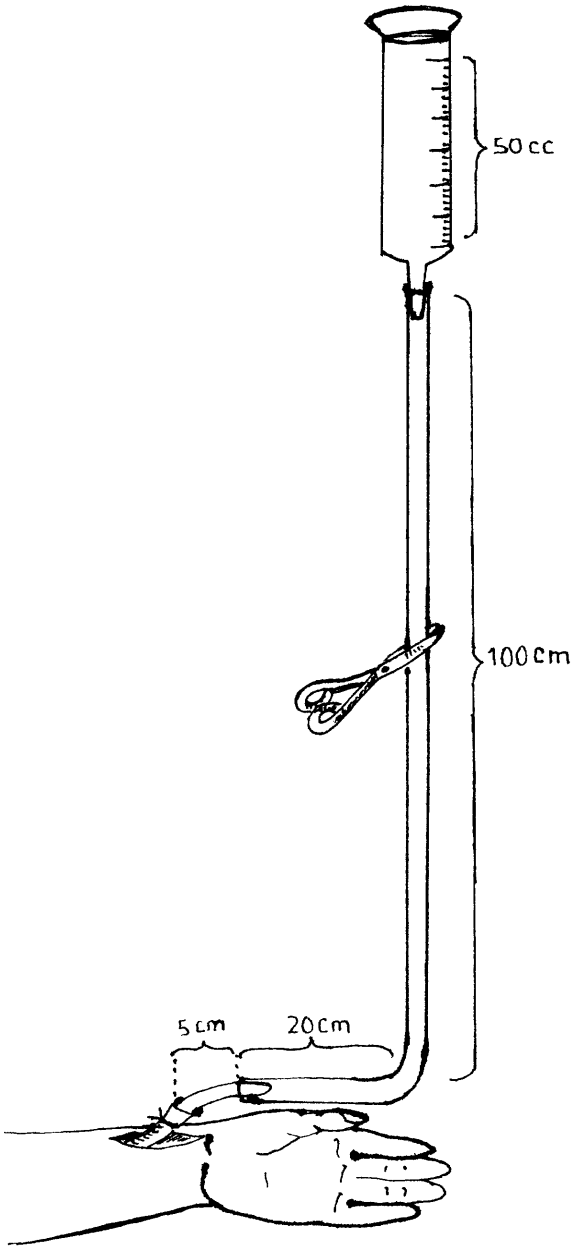

Fig. 1. Schematic presentation of the system developed for the indirect measurement of the venous outflow resistance of the fistula vein just prior to the measurement.

After the AVF was created, fistula flow through the venous side of the fistula was measured by CFDI at the first and the seventh postoperative days. All fistula flow measurements were carried out from the same location which was 1 cm proximal to the created fistula opening, without any compression. Fistula flow rate for each patient was measured repetitively three times, the mean value was recorded, and no intraindividual significant differences were found. Immediate failure was defined as no detectable clinical sign of (i.e. thrill by palpation or auscultation) fistula function at 24 h and no detectable flow at day 1 duplex examination. The patients were followed up to 2–6 months after the construction of the fistulae.

Fisher's exact test, correlation matrix, and multiple regression analysis were used for the evaluation of the probability of possible correlation between the haemodynamic parameters studied (ABP, AI, SVF, VO) and postoperative day 1 AVF flow rate. Fistula maturation in time was evaluated by Wilcoxon test. All statistical analyses were done utilizing SPSS PC+(Statistical Package for the Social Services Personal Computer Enhanced Edition). P values < 0.05 were regarded as statistically significant.

Results

Twenty-two male and 10 female patients, ages ranging between 15 and 82 years were examined. Four had a history of diabetes and one had prior subclavian vein catheterization history on the ipsilateral side with the fistula. The patients with brachiocephalic fistula ($n=5$) had undergone previous radiocephalic AVF constructions, which had eventually failed.

Measurements of preoperative ABP, AI, SVF, operative VO, and postoperative fistula flow (FF) at 1st and 7th days are summarized in Table 1.

Regarding the immediate failures, although the number of patients ($n=4$) are not enough for statistical comparison, preoperative AI and operative VO values were lower than the average value of the whole series in three of four patients. Furthermore, in all immediate failure cases, SVF values were lower than the average value of the whole series. The only patient with ipsilateral subclavian vein catheterization history was also among this immediate failure group.

Graphical documentation of the measured preoperative mean ABP, SVF, AI, and operative VO values

Table 1. Results of haemodynamic measurements in 32 patients

Patient no	Preoperative			Operative	Postoperative fistula flow	
	MABP (mmHg)	Ipsilateral SVF (ml/min)	Arterial inflow (ml/min)	Venous outflow per constant volume and pressure (s)	First day (ml/min)	Seventh day (ml/min)
1	96.6	300	10	40	710	810
2	110	190	10	88	300	320
3	90	190	10	40	360	500
4	96.6	640	10	30	1000	1150
5	93.3	340	10	66	350	600
6	70	230	20	45	190	200
7	93.3	450	20	75	380	410
8	100	600	20	38	350	450
9	110	700	20	140	500	1100
10	73.3	160	20	100	580	1060
11	96.6	60	20	60	950	1040
12	106.6	600	20	65	90	140
13	106.6	450	20	35	440	470
14	93.3	400	20	55	420	730
15[b]	**106.6**	**350**	**20**	**55**	**0**	**0**
16	120	560	20	56	1030	1350
17	**86.6**	**230**	**20**	**30**	**0**	**0**
18	**86.6**	**300**	**20**	**71**	**0**	**0**
19	110	360	30	63	230	250
20	86.6	400	30	43	350	650
21	110	600	30	33	740	880
22[b]	103.3	440	30	70	280	610
23	100	260	30	25	230	460
24	113.3	290	40	52	900	2140
25	120	400	40	40	860	1280
26	96.6	490	40	65	810	990
27[b]	123.3	480	50	56	370	2600
28	106.6	400	50	45	380	590
29	90	440	60	75	850	1540
30[a]	**133.3**	**170**	**60**	**50**	**0**	**0**
31	96.6	230	70	58	800	840
32[b]	96.6	850	80	77	650	900
Average values	101.0	393	30	58	472	861
Standard deviations	13.6	178	18	23	315	565
Ranges	70–133.3	60–850	10–80	25–140	0–1030	140–2600

[a]Subclavian vein catheterization history at the ipsilateral arm; [b]history of diabetes mellitus; MABP, mean arterial blood pressure; SVF, subclavian vein flow; bold figures, immediate failures.

against FF are presented in Figures 2a–d. As can be seen in Figure 2c, among 23 patients with preoperative AI values <40 ml/min; the fistula flow was higher than 600 ml/min in five patients (21%). On the other hand, in patients with preoperative AI values $\geqslant 40$ ml/min (9 patients) the fistula flow was higher than 600 ml/min in six patients (66.6%). This increased fistula flow rate in patients with preoperative AI values $\geqslant 40$ ml/min was also found to be statistically significant by Fisher's exact test ($P=0.0219$). The sensitivity, specificity, positive predictive value, and negative predictive value of the critical preoperative AI rate (40 ml/min) in determining a postoperative fistula flow rate of 600 ml/min was calculated as 54, 85, 66, and 78% respectively. It is also noteworthy that three of four immediate failures occurred in 23 patients with preoperative AI values <40 ml/min. Only one fistula among nine patients with preoperative AI rate $\geqslant 40$ ml/min failed. However, this difference was found to be statistically insignificant by Fisher's exact test ($P=0.44$). Figure 2b shows that all four immediate failures occurred in 15 patients with SVF values <400 ml/min (27%). No immediate failures occurred in the rest of the group in which SVF values were $\geqslant 400$ ml/min (0%), and this difference was also statistically significant by Fisher's exact test ($P<0.05$). Application of this criterion yielded a sensitivity of 100%, specificity of 61%, positive predictive value of 26% and negative predictive value of 100% for the immediate failure of the fistulae. Data in Figures 2a and 2d regarding preoperative mean ABP and operative VO *versus* FF revealed no correlation at all. Temporal increase in the fistula flow rate from postoperative day 1 to postoperative day 7 was found to be statistically significant by Wilcoxon test ($P<0.01$).

The effect of preoperative mean ABP, AI, operative VO and SVF values on the quantity of FF was evaluated with correlation matrix and multiple regres-

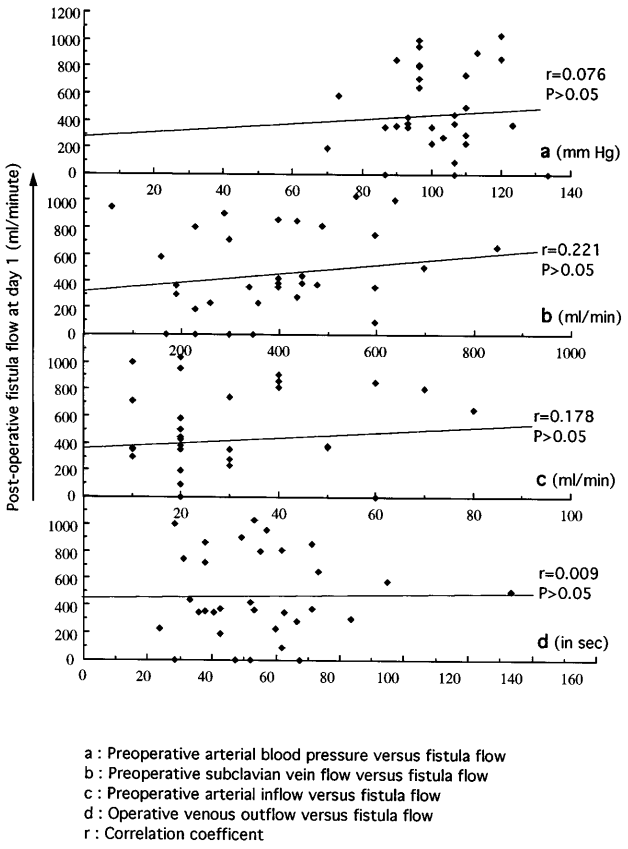

Fig. 2. (a) Graphical documentation of preoperative arterial blood pressure, (b) subclavian vein flow, (c) arterial inflow and operative venous outflow (d) values *versus* postoperative fistula flow rate.

sion analysis and none of the aforementioned haemodynamic parameters was found to affect postoperative fistula flow rate significantly ($P<0.05$). In other words, no linear correlation was found between the measured haemodynamic parameters and the quantity of the AVF flow rate (Figure 2).

All fistulae excluding the immediate failures remained patent and were successfully used for haemodialysis during the follow-up period.

Discussion

Early failure and inadequate flow rates are the most frequent problems associated with AVFs [4,7,9]. Causative factors for poor outcome remain speculative and clarification of factors that may lead to lower flow rates and early failure prior to AVF reconstruction would be of great interest. Such factors, if found, may direct the operation to be performed under more suitable conditions or at better anatomical locations, since most patients require a well-functioning AVF in a short time.

In competent hands of a vascular surgeon, at least in theory; the success of a newly constructed AVF must depend on several haemodynamic variables affecting the inflow and the outflow of the AVF. Hypothetically, higher radial arterial blood pressure, better arterial inflow, a patent subclavian vein with higher flow rates and decreased venous resistance at the fistula arm should be associated with better patency and flow rates after the AVF reconstruction.

Nevertheless, there is a lack of information providing evidence regarding the effect of above-mentioned haemodynamic parameters on postoperative fistula flow rates and early failure. Previous retrospective studies have pointed out that the presence of diabetes, hypotension, reduced size of fistula vein calibre, thrombosis of the subclavian vein and history of subclavian vein catheterization may interfere with the outcome of a newly constructed AVF [1,10–13].

The data regarding the immediate failures is not enough for direct statistical comparison with the rest of the series, since only a small portion of AVF constructions (4/32) were among this group, but it is noteworthy that preoperative AI and operative VO values of 75% of immediate failures were lower than the average of the whole series, and all immediate failures had lower SVF values than the series' average value. Furthermore, careful examination of our data revealed two critical preoperative haemodynamic values concerning immediate failures, which could be statistically tested. Among these, a preoperative AI rate of less than 40 ml/min seemed to be associated with higher rate of immediate failure but this finding was not statistically significant ($P>0.05$). On the other hand, the other critical value of preoperative SVF rate less than 400 ml/min was found to significantly affect the rate of immediate failures ($P<0.05$). No failures occurred in patients with preoperative subclavian vein flow rate of equal to or more than 400 ml/min and this finding, giving a negative predictive value of 100% with 100% sensitivity, may be valuable in determining the immediate success of a planned AVF operation. Thrombosis of the subclavian vein was reported to be associated less favourable AVF outcomes [10–13] and this is quite understandable since the subclavian vein is the sole and ultimate outflow tract of the upper extremity. However, no previous study has evaluated the effect of subclavian venous flow on AVF outcome. The only patient with previous ipsilateral subclavian vein catheterization history in our series had a very low SVF value (170 ml/min) and this patient was among the group of immediate failures, although CFDI failed to visualize the presence of distal subclavian vein thrombosis. As infraclavicular assessment of subclavian vein cannot visualize the proximal portion of the vein, this patient might had a proximally thrombosed vein causing the low flow state distally.

Regarding the effect of haemodynamic variables on the quantity of postoperative fistula flow rate, we failed to document any linear relationship. This is not surprising, however, and points out that (i.e. considering the preoperative AI values); the higher the patients' arterial inflow rate, one can not anticipate a proportionally equal increase in the fistula flow rate. This is because any improvement in the fistula flow rate is always under the influence of factors affecting the outflow as well, and therefore a linear relationship between one

of the haemodynamic parameters and fistula flow rate is almost impossible. Therefore, in order to make use of our collected data, it is important to look for critical values associated with better outcome. Among all measured values, the only significantly important difference regarding better postoperative fistula flow rates was observed in patients with preoperative AI rate of $\geqslant$than 40 ml/min. It is in this group of patients that fistula rates were over 600 ml/min at a rate of 66% giving a positive and negative predictive values of 66 and 78% respectively.

It is known that fistula flow rates just after the AVF operation may provide information regarding future outcome. Elfström *et al.* [14] measured blood flow rates of new primary AVFs and found that initial fistula flow rates of less than 40 ml/min were associated with early failure in 70% of the cases. This finding is in accordance with our first day fistula flow measurements, in which all of our fistula flow rates were higher than this value and none of them failed during the study period. Since immediate flow rate of a newly constructed AVF influences future outcome; the findings of this study deserves more attention as it provides information predicting the early fistula flow rate prior to the fistula operation and thereby the information presented in our study may interfere the surgeons' operation plan. Our results revealed no correlation between preoperative ABP and immediate fistula failure or quantity of the fistula flow. This is somehow in contrast to the previous literature and Thomsen *et al.* [10] reported increased early failure rate in AVFs created in patients with systolic blood pressures less than 110 mmHg. However, Thomsen *et al.*'s study, besides being a retrospective analysis, did not take outflow parameters into account and early failure was described as failure within 2 weeks after the AVF construction. Blood pressure *per se*, as a function of not only the cardiac output but also the peripheral arterial resistance, should not be anticipated as a major AVF outcome determining factor since the overall inflow in an artery may even be nil although the pressure recorded within this very same artery might be quite high.

Regarding our findings about venous outflow resistance, we failed to document any relationship between these values and immediate failure or postoperative fistula flow rates. Clinical diagnosis of outflow restriction of the fistula vein prior to AVF construction is impossible owing to the abundance and individual variability of collateral venous circulation. The intraoperative technique we described in our study provided indirect but important information pointing out individual differences in the venous outflow resistance. However, these differences did not have significant effects on the outcome of the fistulae probably owing to the venous systems' low resistance state in general and the venous anatomy of the arm.

This study also documented that primary fistulae mature, as the differences between the 1st and 7th day fistula flow rates were statistically significant ($P < 0.01$). No previous study has directly documented this increased flow rate in time in a prospective series of patients.

Although the number of patients are small, necessitating further controlled prospective trials on sufficient number of patients, our preliminary results emphasize that preoperative AI rate of the fistula artery and preoperative SVF rate at the fistula arm are important factors influencing the AVF outcome in comparison to the arterial blood pressure and venous resistance at the ipsilateral arm. In patients undergoing primary AVF operations, an arterial inflow rate of 40 ml/min or more and SVF rate of 400 ml/min or more may be associated with less immediate failures and better fistula flow rates. The measurement of preoperative AI and SVF values by CDFI, an easy and non-invasive method, is therefore recommended during the evaluation of patients who are candidates for an internal AVF operation.

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