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PERSPECTIVES IN RENAL MEDICINE

Increasing arteriovenous fistulas in hemodialysis patients: Problems and solutions

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Increasing arteriovenous fistulas in hemodialysis patients: Problems and solutions. National guidelines promote increasing the prevalence of fistula use among hemodialysis patients. The prevalence of fistulas among hemodialysis patients reflects both national, regional, and local practice differences as well as patient-specific demographic and clinical factors. Increasing fistula prevalence requires increasing fistula placement, improving maturation of new fistulas, and enhancing long-term patency of mature fistulas for dialysis. Whether a patient receives a fistula depends on several factors: timing of referral for dialysis and vascular access, type of fistula placed, patient demographics, preference of the nephrologist, surgeon, and dialysis nurses, and vascular anatomy of the patient. Whether the placed fistula is useable for dialysis depends on additional factors, including adequacy of vessels, surgeon's experience, patient demographics, nursing skills, minimal acceptable dialysis blood flow, and attempts to revise immature fistulas. Whether a mature fistula achieves long-term patency depends on the ability to prevent and correct thrombosis. An optimal outcome is likely when there is (*1*) a multidisciplinary team approach to vascular access; (*2*) consensus about the goals among all interested parties (nephrologists, surgeons, radiologists, dialysis nurses, and patients); (*3*) early referral for placement of vascular access; (*4*) restriction of vascular access procedures to surgeons with demonstrable interest and experience; (*5*) routine, preoperative mapping of the patient's arteries and veins; (*6*) close, ongoing communication among the involved parties; and (*7*) prospective tracking of outcomes with continuous quality assessment. Implementing these measures is likely to increase the prevalence of fistulas in any given dialysis unit. However, differences among dialysis units are likely to persist because of differences in gender, race, and co-morbidity mix of the patient population.

Vascular access procedures and complications account for over 20% of hospitalizations of dialysis patients in the United States and cost about $1 billion annually [1, 2]. In an effort to improve vascular access outcomes the National Kidney Foundation published the Dialysis Outcome Quality Initiative (DOQI) guidelines in 1997, a set of evidence-based and opinion-based guidelines regarding the optimal management of vascular access [3]. The DOQI guidelines have stimulated a large body of epidemiologic and clinical studies on vascular access, thereby expanding our understanding of this important topic. One important DOQI guideline has urged nephrologists to increase the number of patients dialyzing with arteriovenous (A-V) fistulas, rather than grafts. The present review summarizes recent clinical research that helps us understand how to achieve this important goal.

Key words: preoperative vascular mapping, graft placement, hemodialysis, end-stage renal disease, thrombosis, dialysis blood flow, vascular access, A-V fistula.

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WHAT IS THE RATIONALE FOR INCREASING FISTULA PLACEMENT?

The relative merits of A-V fistulas and grafts have been a subject of ongoing investigation and debate for many years. Thirty years ago, patient selection for dialysis was relatively stringent, and most patients were young, non-diabetic men with minimal co-morbidity (Table 1). Within this select population, the arteries and veins were generally well preserved and permitted construction of native A-V fistulas in the wrist. The expectation was that the vast majority of fistulas placed would mature adequately to be used for dialysis, and subsequently remain patent and useable for dialysis for many years with minimal intervention. In addition, up until the mid-1980s the median dialysis blood flow in the United States was about 250 mL/min [4], such that even relatively small diameter fistulas could deliver the desired flows.

In recent years, as a result of more liberal selection criteria, the chronic dialysis population has become substantially older, more likely to be female and diabetic, and has higher co-morbidity, including extensive atherosclerotic vascular disease (Table 1). Many of these patients appear to have poor vessels for construction of native fistulas. Concurrently, increased emphasis on dial-

Table 1. Hemodialysis patient characteristics in the United States (1967 and 1999) and in Europe (1999)

	1967 (US)	1999 (US)	1999 (Europe)	*P* value[a]
Female gender %	25	47	43	0.03
Black race %	9	38	1	<0.001
Age, mean ± SD		60.5 ± 15.5	60.7 ± 15.2	NS
Age >65 years %	7	50		
Diabetes %	<5	46	22	<0.001
Coronary artery disease %	26	51	31	<0.001
Cerebrovascular disease %		19	13.5	<0.001
Peripheral vascular disease %		23	19	0.005
Congestive heart failure		48	23	<0.001

U.S. data for 1967 are adapted from [60] and [61]. U.S. and European data for 1999 are adapted from [18] and Goodkin et al (abstract, *J Am Soc Nephrol* 10: 242A, 1999). NS is not significant.
[a] Comparison between United States and Europe in 1999

ysis adequacy (Kt/V) has led to the recognition that higher blood flows can improve urea clearance, and thereby permit delivery of adequate dialysis to larger patients without entailing substantial increases in dialysis times. These considerations have led to increased utilization of A-V grafts and decreased use of A-V fistulas. By the mid-1990s only 20% of patients in the United States were dialyzing with fistulas [5].

With the growing use of A-V grafts, it became evident that the prosthetic vascular access is prone to an alarming frequency of thrombosis [6]. Further investigation led to the observation that graft thrombosis usually arises from progressive stenosis at the venous anastomosis or the draining vein, and that prophylactic angioplasty of stenotic lesions decreases the frequency of graft thrombosis substantially [7–11]. Recognition of the value of elective angioplasty led to considerable research on monitoring methods for detection of hemodynamically significant graft stenosis [2]. Nonetheless, it became clear that graft stenosis is a frequent and recurrent process, and that monitoring and intervention to prevent graft thrombosis is costly and labor intensive [2].

Arteriovenous fistulas once again came into favor due to their lower frequency of stenosis, thrombosis, and infection, as compared to A-V grafts. In this context, the DOQI vascular access guidelines advocated intensive efforts to increase the prevalence of fistula use among dialysis patients [3]. These guidelines recommend attempting fistula placement in at least 50% of patients, with A-V grafts being reserved for patients whose vascular anatomy does not permit construction of a native A-V fistula. DOQI guidelines predict that such a strategy will result in 40% of prevalent patients dialyzing with a fistula.

A major hurdle in achieving this goal is the high frequency of new A-V fistulas that are never useable for dialysis (primary failures) either due to early thrombosis or due to lack of maturation. A deliberate policy of placing A-V fistulas in the majority of dialysis patients, many of whom have marginal vessels, necessarily increases the frequency of primary failure. Whereas studies from 20 to 25 years ago observed a primary fistula failure rate of about 10%, more recent investigations have typically reported a 20 to 50% primary failure rate (Table 2). The primary (intervention-free) survival of fistulas at one year was better than that of grafts in some studies, but not in others (Table 2). These comparisons are often misleading, because some investigators have specifically excluded fistulas that never matured, whereas others have included primary failures, when calculating primary

Table 2. Short-term outcomes of fistulas

	N accesses		Primary failures %		Primary (unassisted) survival at 1 year %	
Citation	Fistula	Graft	Fistula	Graft	Fistula	Graft
Kinnaert, 1977 [62]	314		9		80	
Bonalumi, 1982 [63]	177		10		83	
Reilly, 1982 [64]	150		11		80	
Palder, 1985 [65]	154		24			
Winsett, 1985 [66]	273		27			
Kherlakian, 1986 [21]	100	100	12	4	71	75
Churchill, 1992 [67]	227	120			82-87	45-67
Coburn, 1994 [20]	59	47			90	70
Rocco, 1996 [23]	48	40	31	12	55	60
Wong, 1996 [48]	60		30			
Miller, 1997 [34]	75	23			84	47
Hodges, 1997 [68]	87	236	43		43	41
Silva, 1998 [51]	108		26		83	74
Hakaim, 1998 [38]	58		22			
Golledge, 1999 [69]	107		18		69	
Miller, 1999 [25]	101		53			
Konner, 2000 [70]	347		2		77	
Ascher, 2000 [52]	99		18			
Murphy, 2000 [71]	74		32			
Renavur, 2000 [72]	137		22		74	
Wolowczyk, 2000 [45]	208		20		65	
Gibson, 2001 [35]	130	92	23		56	36
Allon, 2001 [13]	139	78	46	21	42	43
Oliver, 2001 [12]	115	80	26	15	65	47
Sedlacek, 2001 [43]	140		25			
Dixon, 2002 [26]	205	117	30	23	53	27
Pisoni, 2002 [18]	177	251			68	49

Primary failure is defined as thrombosis or failure to mature adequately for dialysis, while primary survival is time from access placement to initial intervention.

Table 3. Long-term outcomes of arteriovenous (A-V) fistulas versus grafts

	Cumulative survival at 1 year %			Revision rate *per access-year*			Infection rate %		
Citation	F	G	Ratio (G/F)	F	G	Ratio (G/F)	F	G	Ratio (G/F)
Winsett, 1985 [66]				0.06	0.44	7.3	<1	12	>12
Palder, 1985 [65]	63	82	1.30					22	
Kherlakian, 1986 [21]							2	12	6.0
Churchill, 1992 [67]							4.5	19.7	4.4
Coburn, 1994 [20]	87	64	0.74				3.4	16.1	4.7
Rocco, 1996 [23]	78	88	1.13	0.34	0.80	2.4	0	6.2	
Miller, 1997 [34]	83	73	0.88	0.17	1.17	6.9			
Hodges, 1997 [68]	46	59	1.28	0.07	0.50	7.1	0	9	
Gibson, 2001 [35]	72	58	0.80			2.9			
Oliver, 2001 [12]	65	68	1.05	0.55	2.4	4.4	2	12	6.0
Allon, 2001 [13]	44	48	1.09	0.57	1.67	2.9			
McCarley, 2001 [11]				0.18	0.80	4.4			
Dixon, 2002 [26]	61	54	0.88	0.45	1.80	4.0			

Only studies reporting outcomes of both fistulas and grafts have been included. Abbreviations are: F, fistula; G, graft. Cumulative survival is defined as time from access placement to permanent failure of access despite revisions; revision rate is angioplasty, thrombectomy, and surgical revisions.

patency. Given the higher rates of non-maturation of fistulas as compared with grafts, the two types of calculations lead to different conclusions. Thus, for example, Oliver et al reported that the primary patency of fistulas was superior to that of grafts, when primary failures were excluded [12]. However, when primary failures were included, the primary patency of fistulas and grafts was comparable during the initial year.

Similarly, studies comparing the cumulative survival (time from access placement to permanent failure) at one year of fistulas and grafts have yielded contradictory results (Table 3). Again, these discrepancies can be attributed to discrepancies in the primary failure rates of fistulas as compared with grafts, as well as whether primary access failures were included in the calculations of access survival. Oliver et al reported that, when primary failures were excluded, the cumulative patency of fistulas was superior to that of grafts [12]. However, when primary failures were included, the cumulative patency of fistulas and grafts was comparable at one year (Fig. 1). The equivalent outcome occurred because the higher primary failure rate of fistulas was offset by the lower rate of subsequent failures. Similar observations on the relative short- and long-term outcomes of fistulas and grafts have been reported by our institution [13].

Despite the comparable cumulative survival of fistulas and grafts, the major advantage of fistulas over grafts is the lower frequency of interventions and complications, once they mature. Maintaining long-term graft patency requires a 2.4- to 7.1-fold higher frequency of salvage procedures (angioplasty, thrombectomy, and surgical revision; Table 3). Moreover, access infections occur substantially more frequently in grafts as compared to fistulas (Table 3). In the short-term, placing a fistula requires a greater investment, due to the higher primary failure rate and much longer time to maturation. The long-term payoff, however, is prolonged patency with far fewer interventions, complications, and expenditures.

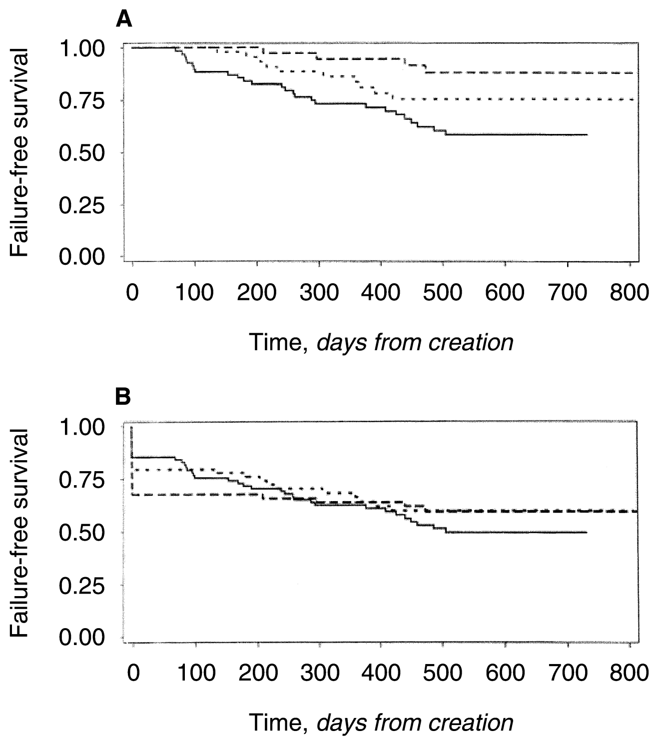

Fig. 1. Failure-free survival (cumulative patency) of brachiobasilic fistulas (dotted line), brachiocephalic fistulas (dashed line), and upper arm grafts (solid line) excluding (*A*) and including primary failure (*B*). When primary failures are excluded, survival of brachiocephalic and brachiobasilic fistulas are comparable to each other, and both are better than for grafts. When primary failures are included, the survival rates for all three types of vascular access are comparable. (Reproduced with permission from the International Society of Nephrology [12].)

A major clinical challenge is to optimize the approach to constructing A-V fistulas, so as to maximize the proportion of patients receiving a fistula while minimizing the proportion of fistulas that never mature. The goal of the present review is to examine critically the reasons underlying the discrepancy between the goals and reality. Specifically, we will examine the clinical and logistic obstacles to increasing the prevalence of fistulas among hemodialysis patients. We will also address specific measures that have been documented to improve vascular access outcomes at selected institutions.

WHAT FACTORS AFFECT FISTULA PREVALENCE IN DIALYSIS PATIENTS?

Geographic variations

Practice patterns can have a major impact on the prevalence of patients dialyzing with fistulas. In a landmark study Hirth et al reported substantial geographic variations in the prevalence of fistulas among new dialysis patients within the United States, ranging from a high of 77% in New England to a low of 15% in the Southeast [14]. Similarly, analysis of a cohort of 1824 patients enrolled in the HEMO Study at 45 American dialysis units found substantial geographic variations [15]. The prevalence of fistulas was 45.3% in the Northeast, but only 30.6% in the Southeast. In both reports, these geographic differences persisted even after adjustment for multiple demographic factors and co-morbid conditions. Variations in the type of vascular access are also reflected in the 2000 Annual Report of ESRD Clinical Performance Measures [16]. During the fourth quarter of 1999, 27% of U.S hemodialysis patients were using fistulas. The prevalence of fistulas varied greatly among the 18 networks, ranging from a low of 15% to a high of 47%.

There are also substantial differences among countries. The Dialysis Outcomes and Practice Patterns Study (DOPPS) [17] reported that only 24% of U.S. patients were dialyzing with fistulas, as compared with 80% among dialysis patients in five European countries (Germany, France, Italy, Britain, and Spain) [18]. Lower comorbidity among European dialysis patients (Table 1) may account for some of the difference. However, it is likely that variations in practice patterns also play a major role.

Variations in fistula prevalence are not limited to comparisons among countries or large geographic regions. They are also evident when one compares individual dialysis units within a single metropolitan area (Fig. 2) [15]. For example, the prevalence of fistulas at five dialysis units in one metropolitan area (Center 11) was 28.6, 43.8, 50.0, 58.8, and 76.7%, respectively. Similarly, the DOPPS Study reported that fistula use varied from 0 to 87% among individual American dialysis units, and from 39 to 100% among individual European units [18]. Such differences may reflect the individual preferences or skill level of the surgeons, nephrologists, and dialysis unit staff. One study reported that in 35% of U.S. dialysis units the dialysis staff preferred grafts over fistulas [19].

Patient factors

Several demographic and clinical factors have been associated with a lower prevalence of fistulas, even after adjustment for geographic region and dialysis unit. Numerous studies have reported that female patients are much less likely than males to dialyze with a fistula [14, 15, 18, 20–23]. The 2000 Annual Report of ESRD Clinical Performance Measures found that nationwide, the prevalence of fistulas among women was only 18%, as compared to 35% in men (Fig. 3) [16]. This discrepancy between the genders was observed in each of the 18 U.S. networks.

Similarly, a number of recent studies have observed a lower prevalence of fistulas used for dialysis among blacks than whites [12, 15, 23, 24]. Hirth et al did not observe a difference in the frequency of fistulas between black and white dialysis patients [14]. However, they reported the type of vascular access present in the patient's arm 30 days after initiation of dialysis, regardless of whether the access was actually useable for dialysis. It is unclear whether the prevalence of *useable* fistulas differed among races. In a recent nationwide survey, fistulas were being used in 23% of black patients, as compared with 29% of whites (Fig. 4) [16]. Examination of individual U.S. networks revealed a lower prevalence of fistulas in blacks than whites in 15 of the 18 networks. Fistula prevalence was equivalent or slightly higher in blacks than whites in only two networks. A comparison was not possible in one network, because its black population was too small to perform a valid statistical comparison. A recent investigation from the United Kingdom also observed that black patients were significantly less likely to dialyze with a fistula than were whites (abstract; Fan et al, *J Am Soc Nephrol* 12:288A, 2001).

Age is an additional independent factor associated with the prevalence of fistulas [14, 15, 18, 23, 24]. Nationwide, the prevalence of fistulas among U.S. hemodialysis patients was 35% in adult patients under age 45, 31% in patients aged 45 to 54 years, 26% in patients ages 65 to 74, and 23% among patients 75 or older [16]. The inverse relationship between age and frequency of fistula use was evident in each of the 18 networks.

Diabetes has been associated with a lower prevalence of fistulas in some studies [14, 18, 24], but not in others [15, 23]. Nationwide, only 22% of U.S. diabetic hemodialysis patients were using fistulas, as compared with 30% of non-diabetic patients [16]. There is controversy as to whether diabetes is an independent risk factor for lower fistula prevalence [14], or whether it is a marker for other associated clinical or co-morbid conditions, such

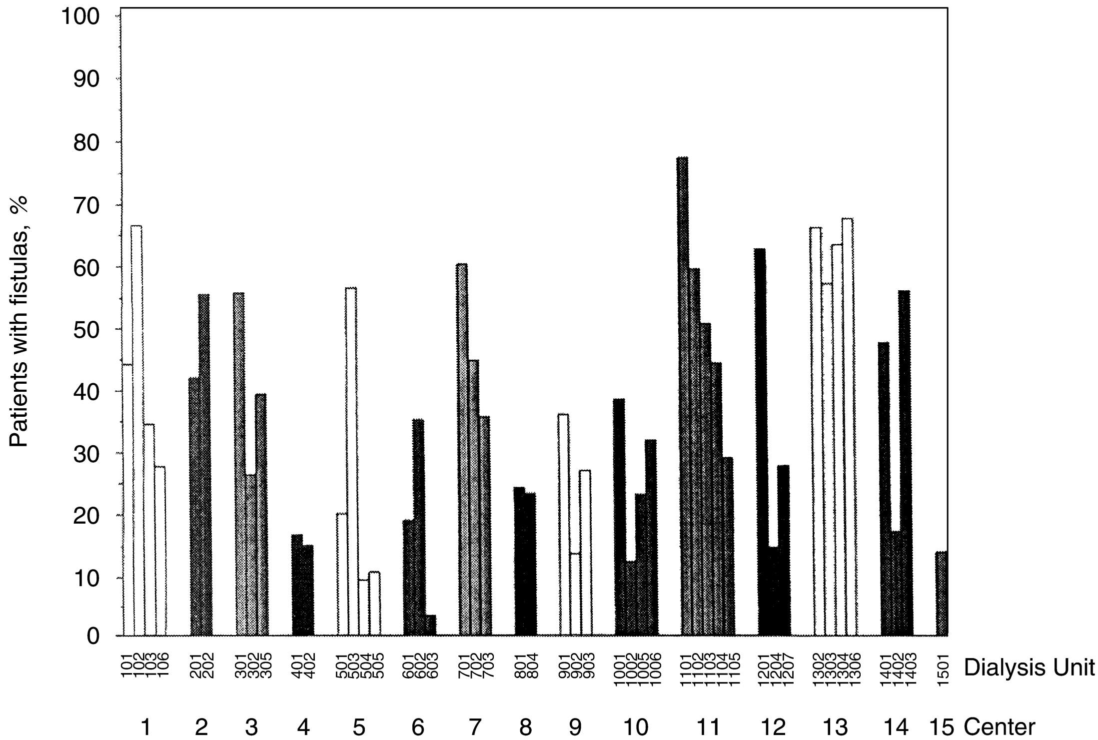

Fig. 2. Frequency of fistula use among the hemodialysis units in the HEMO Study. The dialysis units are sorted with the 15 clinical centers with which they are affiliated. The dialysis units in a given clinical center are located in a single metropolitan area. There are large variations in the prevalence of fistula use among individual dialysis units. (Reproduced with permission from the International Society of Nephrology [15].)

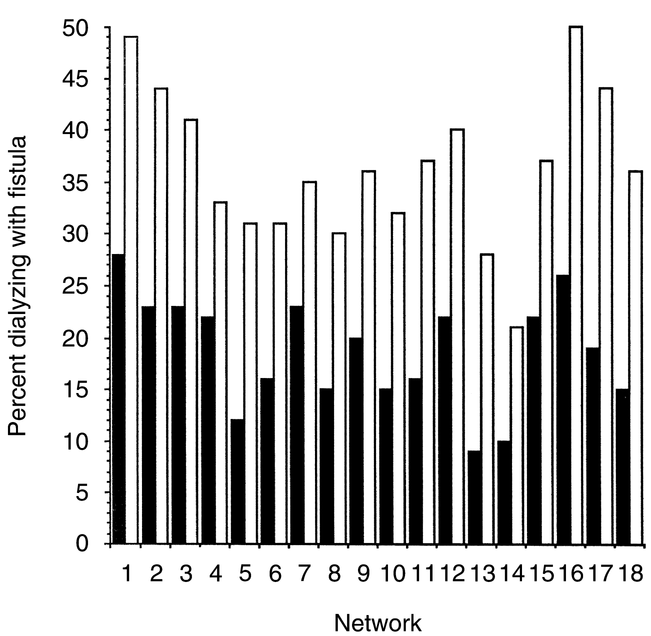

Fig. 3. Percent of U.S. patients dialyzing with fistulas in October to December 1999, sorted by patient gender and dialysis network. Symbols are: (■) female patients; (□) male patients. Overall fistula prevalence varies greatly among networks, but in each of the 18 networks, fistula use is lower among women than men. (Adapted from [16].)

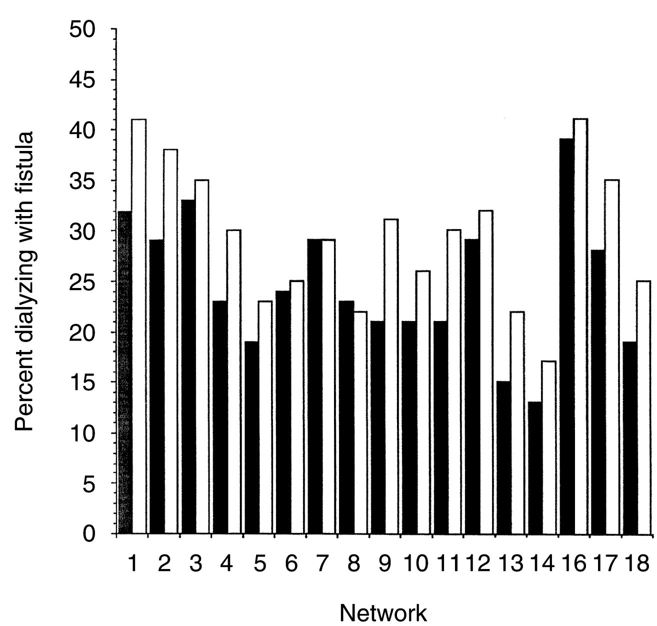

Fig. 4. Percent of U.S. patients dialyzing with fistulas in October to December 1999, sorted by patient race and dialysis network. Symbols are: (■) black patients; (□) white patients. Overall fistula prevalence varies greatly among networks, but in nearly each individual network, fistula use is lower among blacks than whites. Network 15 had too few black patients to be included in the analysis. (Adapted from [16].)

as female gender, older age, black race, obesity, and presence of peripheral vascular disease [15].

Other factors that have been associated with a lower fistula prevalence include presence of peripheral vascular disease [14, 15, 18, 21], obesity [15, 18, 24], and lower socioeconomic status [14].

Practice patterns

Successful, long-term use of a fistula for dialysis requires overcoming at least four hurdles. First, the surgeon must be able and willing to place an A-V fistula. Second, the newly constructed fistula must mature sufficiently to be cannulated reproducibly with large-bore needles and deliver an acceptable dialysis blood flow. Third, the dialysis staff must be proficient in cannulation of fistulas. Finally, the mature fistula must remain patent with minimal requirements for further interventions. Problems occurring at each of these levels can have a cumulative negative effect on the overall prevalence of patients dialyzing with fistulas. Increasing fistula prevalence requires a clear understanding of the factors contributing to the problem, and aggressive efforts to overcome these roadblocks. The next few sections will address the specific variables that determine whether a patient receives a fistula, whether the fistula matures, and whether it achieves long-term patency for dialysis.

FACTORS AFFECTING FISTULA PLACEMENT

Timing of fistula placement

The mean maturation time of new A-V fistulas is about two to four months [12, 13, 25, 26]. Moreover, patients whose fistula fails to mature adequately to be used for dialysis require subsequent interventions to promote fistula maturation, or alternatively, construction of another vascular access. If the patient is already on dialysis, fistula placement entails prolonged hemodialysis with a temporary dialysis catheter with all its attendant complications, including poor blood flows, frequent thrombosis or malfunction, and life-threatening bacteremia [27]. Clearly, these issues can be avoided when the fistula has been constructed in a timely fashion in pre-dialysis patients, so that it is ready for use prior to the need for maintenance dialysis. In this regard, the DOQI guidelines recommend referring patients for fistula placement when the serum creatinine is >4 mg/dL or the creatinine clearance <25 mL/min [3].

At initiation of dialysis, 66% of U.S patients use a catheter, 22% use a graft, and only 12% use a fistula. Sixty days after initiation of dialysis, 32% still dialyze with a catheter, 49% with a graft, and 19% with a fistula. Of those patients who started dialysis with a catheter, but were dialyzing with a permanent access at 60 days, only 25% were using a fistula, whereas 75% had a graft [24]. Despite the DOQI guidelines, many patients with chronic kidney disease are not referred to a nephrologist until their renal failure is very advanced. Even among those patients with early referral (at least 4 months before initiation of dialysis), a substantial proportion still do not get a permanent vascular access prior to initiation of dialysis. Arora et al reported that a functioning permanent vascular access at initiation of dialysis is found in 40% of patients with early referral to a nephrologist, but only 4% of patients with late referral [28]. Moreover, the first vascular access is more likely to be a fistula than a graft in patients with an early referral than those referred late (45 vs. 31%) [29]. Similar observations have been reported from Europe. A recent French study noted that among patients with late referral, 73% initiated dialysis with a catheter, and only 12% with a fistula. In contrast, among patients with early referral, 29% initiated dialysis with a catheter, and 53% with a fistula [30]. At the time of initiation of dialysis, only 15% of U.S. patients use fistulas, as compared with 66% of European patients [18]. Differences in health coverage among countries may contribute to this discrepancy. Universal health coverage, which is common in most European countries, promotes comprehensive medical care and early referral to nephrologists and surgeons. In contrast, a substantial proportion of patients with chronic kidney disease in the U.S. do not qualify for health coverage until they initiate dialysis.

Type of fistula placed

The original type of fistula described was the radiocephalic fistula (Fig. 5), which involves a direct anastomosis of the radial artery and cephalic vein at the wrist [31]. Many patients without suitable vessels in the forearm may be good candidates for construction of a brachiocephalic fistula in the upper arm (Fig. 6). Because the cephalic vein is frequently cannulated in the antecubital space for phlebotomy, the resulting stenosis or thrombosis may preclude its use for construction of a fistula. The basilic vein, which runs deeper and is spared from phlebotomy, often has a large enough diameter to permit its use for fistula construction. However, its depth from the skin would preclude cannulation of a brachiobasilic fistula in the native position. To overcome this difficulty, the basilic vein can be dissected out and tunneled in the subcutaneous tissue of the anterior upper arm, easily accessible with a dialysis needle (Fig. 7). The invention of the transposed brachiobasilic fistula [32] has further expanded the proportion of patients in whom construction of a native fistula is feasible. Finally, Polo et al recently described construction of a brachiocephalic jump graft fistula, whereby a short polytetrafluoroethylene (PTFE) segment is tunneled subcutaneously and anastomosed to the brachial artery and cephalic vein through two short skin incisions [33]. They reported a

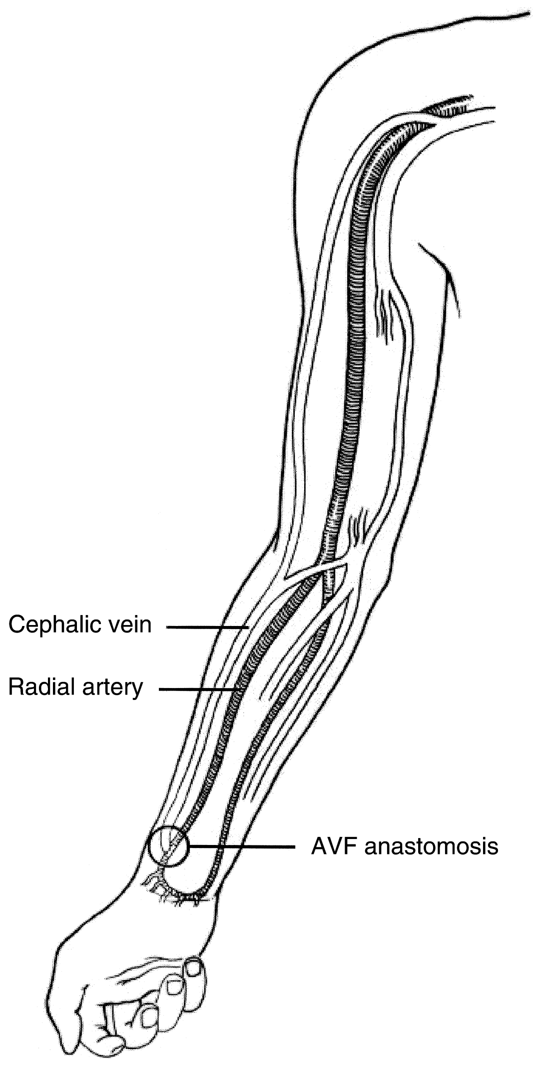

Fig. 5. Radiocephalic arteriovenous (A-V) fistula.

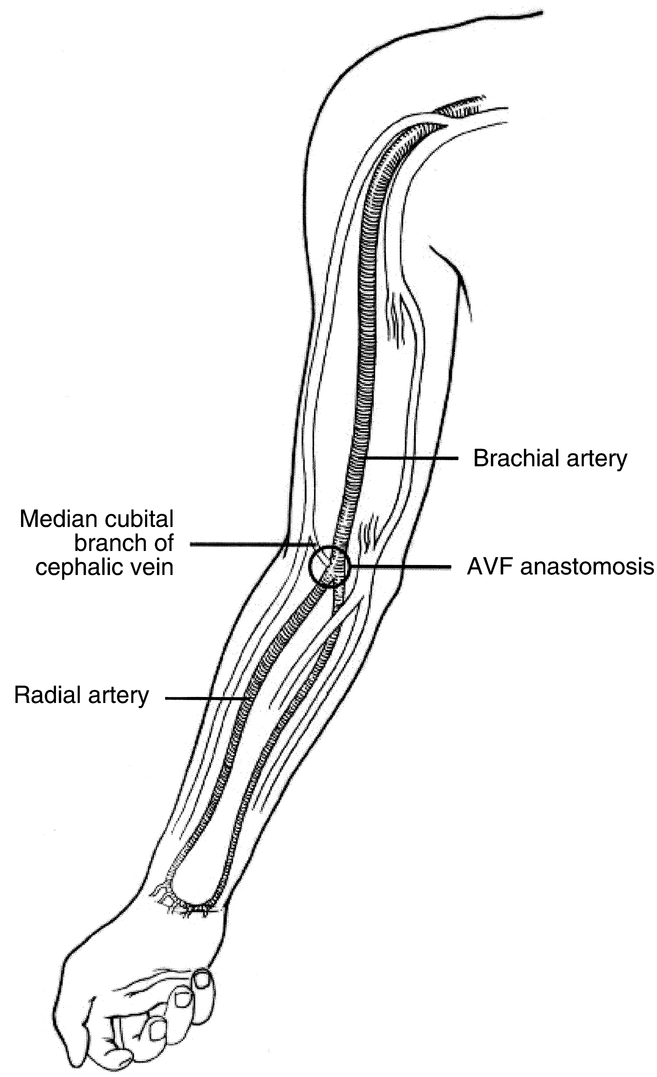

Fig. 6. Brachiocephalic A-V fistula.

primary patency rate of 85% at one year, comparable to that observed with "pure" upper arm fistulas.

The majority of dialysis patients can have a native fistula placed as their initial vascular access, provided that there is a willingness to consider all three types of fistulas, and to use preoperative vascular mapping to identify suitable vessels for their construction. Using objective sonographic criteria at our institution, a forearm (radiocephalic) fistula was placed in 48% of the patients. An additional 29% of the patients received an upper arm fistula (brachiocephalic or brachiobasilic), because a forearm fistula was not feasible. Thus, some type of native fistula could be constructed in 77% of patients, and only 23% received an A-V graft [13]. Miller et al could place a fistula in 76.5% of patients, including 42% in the forearm and 34.5% in the upper arm [34]. Dixon, Novak and Fangman reported that a fistula was possible as a primary access in 73% of patients (36% in the forearm and 37% in the upper arm), whereas only 27% required grafts [26]. Finally, Gibson et al were able to place an A-V fistula in 95% of patients (almost exclusively men) [35].

The likelihood of placing a secondary fistula among patients with at least one failed vascular access is considerably lower. Among this high-risk population, we found that a fistula was possible in only 39% (28% in the forearm and 11% in the upper arm), whereas 61% required a graft [13].

Patient demographics

The likelihood of having a fistula placed can vary substantially among different patient subgroups (Table 4). Numerous studies have reported that fistula placement is less frequent among women than men, and a few recent studies suggest that fistula placement is less likely among black than white patients. We found that female gender

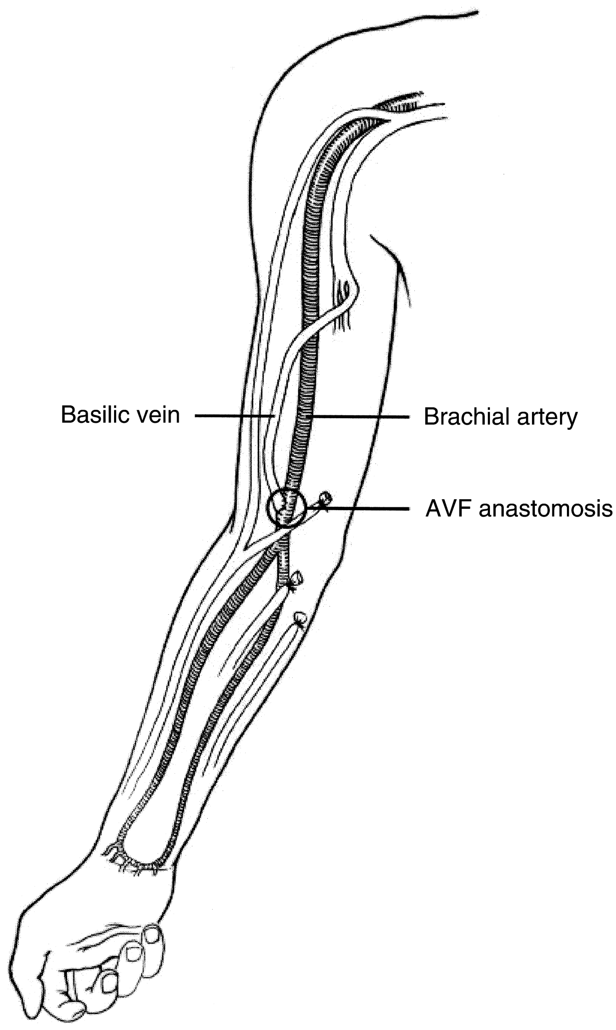

Fig. 7. Brachiobasilic transposition A-V fistula.

and black race were independent predictors of a lower likelihood of fistula placement. Using objective preoperative vascular measurements, a fistula could be placed in only 43% of black women, as compared with 92% of white men [13].

Moreover, the initial fistula is more likely to be placed in the upper arm, rather the forearm, when the patient is female or black. Using objective preoperative sonographic criteria, we found that the initial fistula placement was in the upper arm in 64% of women, as compared with 36% of men. Similarly, fistula construction in the upper arm occurred in 54% of black patients, as compared with 34% of whites [13].

The effect of diabetic status on fistula placement is controversial. Whereas some studies have observed substantially lower fistula placement in diabetic, as compared with non-diabetic patients, other investigators have found little or no difference (Table 4).

FACTORS AFFECTING FISTULA MATURATION

Adequacy of vessels and type of fistula

Several changes are critical for the successful maturation of a new fistula [36]. First, it must dilate to a caliber large enough to be cannulated repeatedly with two large-bore dialysis needles. Second, the blood flow rate in the draining vein must increase sufficiently to accommodate the dialysis blood flow required to deliver adequate dialysis. To avoid vein collapse and recirculation, the access blood flow should exceed the desired dialysis blood flow by at least 100 mL/min. The mean dialysis blood flow varies substantially among countries: about 400 mL/min in the United States, 300 mL/min in Europe, and 200 mL/min in Japan (abstract; Dykstra et al, *J Am Soc Nephrol* 11:182A, 2000). All other factors being equal, this means that patients in Europe and Japan require substantially longer dialysis times than American dialysis patients to achieve comparable Kt/V values. These differences also mean that the definition of a mature fistula can vary among countries. A fistula that is deemed adequate in Japan or Europe when it delivers a dialysis blood flow of 200 to 300 mL/min may be considered inadequate in the United States. Using ultrasounds of fistulas obtained one to four months postoperatively, we observed that 40% of fistulas had an access flow rate <500 mL/min [37]. Clearly, a lower proportion of such fistulas would be deemed adequate for dialysis in the U.S., as compared with Europe or Japan. Third, the wall of the draining vein must hypertrophy sufficiently to seal after withdrawal of the dialysis needle. Finally, the fistula must be superficial enough for the landmarks to be appreciated and permit safe cannulation without infiltration.

There is marked variation in the published literature regarding the definition of a "successful" fistula. The definitions have included presence of a thrill or bruit, ability to use the fistula for at least one dialysis session, or ability to use the fistula reproducibly for dialysis for at least one month with a dialysis blood flow >350 mL/min. Not surprisingly, the adequacy rate of fistulas is lower when a more stringent definition is used. Fistulas have a relatively high rate of primary failure (Table 2), due to either early thrombosis or failure of the draining vein to dilate adequately to mature, that is, be cannulated and provide a reasonable dialysis blood flow reproducibly. In the absence of preoperative vascular mapping, the rate of primary failure may be substantially higher in forearm, as compared to upper arm fistulas. We reported a primary failure rate of 66% in forearm fistulas, as compared with 41% among upper arm fistulas [25]. Similarly, Hakaim, Nalbandian and Scott observed a 70% non-maturation rate for forearm fistulas among diabetic dialysis patients, as compared with 22% for upper arm fistulas [38]. Finally, Bender, Bruyninckx and Gerlag reported a primary one-year patency of 76% in forearm

Table 4. Likelihood of fistula (rather than graft) placement by clinical characteristics

	Gender			Race			Diabetic status		
Citation	Female %	Male %	Ratio	Black %	White %	Ratio	Yes %	No %	Ratio
Winsett, 1985 [66]							13	25	0.52
Kherlakian, 1986 [21]	40	59	0.68				46	51	0.90
Churchill, 1992 [67]	51	74	0.69				64	66	0.97
Coburn, 1994 [20]	48	61	0.79				58	53	1.09
Rocco, 1996 [23]	40	72	0.56	47	68	0.69	41	61	0.67
Miller, 1999 [25]	22	44	0.50				27	36	0.75
Sedlacek, 2001 [43]							66	60	1.10
Oliver, 2001 [12]	41	65	0.63	55	68	0.81	46	78	0.59
Allon, 2001 [13]	50	74	0.68	54	86	0.63	63	65	0.97

fistulas, as compared with 93% among upper arm fistulas [39]. A deliberate policy at one center of placing upper arm fistulas in preference to forearm fistulas resulted in a substantial increase (from 28 to 44%) in the prevalence of patients dialyzing with fistulas [40].

There are contradictory conclusions as to whether the outcomes of secondary fistulas are different from those of primary fistulas. Using preoperative sonographic vascular mapping, we observed similar maturation rates of primary and secondary fistulas (53 vs. 54%) [13]. In contrast, Gibson et al reported that primary access failures were about 40% lower among primary than secondary fistulas [35].

Several small European studies have observed a lower rate of early fistula thrombosis among patients treated with anti-platelet agents started preoperatively and continued for three to six weeks [41]. A large prospective, randomized study is clearly warranted to address this important clinical question.

Patients are frequently encouraged to perform regular hand exercise to promote maturation of a new fistula. There is no published research confirming the efficacy of this maneuver. The only study addressing this question failed to demonstrate a significant increase in A-V fistula flow during hand exercise in 40 patients with renal failure [42].

Finally, the experience of the surgeon is also an important factor determining fistula outcome. Dixon, Novak and Fangman recently reported that fistula patency was worse if it was placed by an inexperienced surgeon (<12 access procedures) than if it was placed by an experienced surgeon [26]. Similarly, Pisoni et al found that a successful fistula was less likely if a surgery trainee performed or assisted in the access procedure [18]. These findings suggest that vascular access surgery should be restricted to surgeons with a strong interest and who perform a large number of access procedures.

Patient demographics

Fistula maturation varies substantially among different demographic groups. Prior to the use of preoperative vascular mapping, we found that new forearm fistulas were useable for dialysis in only 7% of women, 12% of elderly patients, and 20% of diabetics. In contrast, the respective maturation rates of upper arm fistulas for these patient subsets were 56%, 54%, and 48%, respectively [25]. When we began using objective sonographic vascular mapping to guide access placement, we discovered that vessels suitable for construction of a forearm fistula were less likely among women and blacks [13].

Once we began using routine preoperative vascular mapping to assist the surgeons in planning vascular access, we found no association between patient age, race, diabetic status or body mass index and the likelihood of fistula maturation. On stepwise logistic regression analysis, female sex was the only independent predictor of decreased likelihood of fistula maturation [13]. In agreement with these observations, Sedlacek et al observed similar maturation rates of fistulas among diabetic and non-diabetic patients [43].

FACTORS AFFECTING LONG-TERM PATENCY OF MATURE FISTULAS

Type of fistula

Dixon et al observed superior one-year primary patency (62 vs. 44%) and secondary patency (69 vs. 52%) of upper arm fistulas as compared with forearm fistulas [26]. The recent increase in utilization of brachiobasilic transposition fistulas has led to studies comparing their outcomes to those of A-V grafts and brachiocephalic fistulas. Coburn and Carney reported that the primary patency at one year of brachiobasilic fistulas was 90%, as compared with 70% of upper arm grafts [20]. Moreover, the grafts had a complication rate 2.5-fold higher than the fistulas. The primary failure (lack of maturation) rates are comparable for brachiobasilic and brachiocephalic fistulas: 21 vs. 22% in one study [38], and 21 vs. 32% in a second report [12]. Recently, Oliver et al compared the survival of upper arm brachiocephalic fistulas, transposed brachiobasilic fistulas, and upper arm grafts at one institution [12]. Excluding primary failures, thrombosis-free survival at one year was 50% for grafts, 77% for

Table 5. Overall success rate in achieving adequate (useable) fistulas when preoperative vascular mapping is used

	Proportion of all patients with fistula placed	Proportion of fistulas that were useable	Proportion of all patients with useable fistula	Fist prevalence in U.S., 1999
All patients	0.64	0.54	0.34	0.27
Sex				
Female	0.50	0.44	0.22[a]	0.18
Male	0.74	0.60	0.44	0.35
Race				
Black	0.54	0.54	0.29[b]	0.23
White	0.86	0.52	0.45	0.29
Age				
>65 years	0.62	0.42	0.26	0.23
<65 years	0.64	0.56	0.36	0.31
Diabetes				
Yes	0.63	0.49	0.31	0.22
No	0.65	0.59	0.38	0.30

First three columns are adapted from [13] and the last column from [16].
[a] $P < 0.001$, [b] $P = 0.02$

brachiobasilic fistulas, and 93% for brachiocephalic fistulas. Thus, brachiobasilic fistulas were superior to synthetic grafts, but inferior to brachiocephalic fistulas. Excluding primary failures, the cumulative (assisted) survivals of brachiobasilic and brachiocephalic fistulas were comparable to each other, and superior to that of A-V grafts (Fig. 1) [12]. When primary failures were included, the cumulative survival was comparable for all three types of vascular access (Fig. 1). However, the intervention rates per access-year to achieve long-term patency were 2.4 for grafts, 0.7 for brachiobasilic fistulas, and 0.4 for brachiocephalic fistulas.

The DOPPS Study reported that primary patency of fistulas was lower in the United States than in Europe (68 vs. 83%) [18]. The reason for this discrepancy remains to be elucidated, but possible explanations may include differences in patient co-morbidity or skill of the dialysis staff in fistula cannulation. In addition, the primary patency of fistulas was inferior among patients starting dialysis with a catheter, as compared with patients who initiated dialysis therapy with a mature fistula [18].

Patient demographics

The primary patency (time from placement to first intervention) of fistulas varies among different patient subsets. Gibson et al reported that intervention-free survival of fistulas was clearly better than that of grafts for white men and younger men [35]. In contrast, the differences between the primary patencies of fistulas and grafts were not significant among black men or older men. Since this study was performed at a Veterans Hospital, the investigators were unable to address potential differences in fistula maturation between men and women. However, Astor et al reported that intervention-free survival was identical between fistulas and grafts among female dialysis patients [44]. Primary access survival was superior for fistulas among male patients, but this advantage was limited to men younger than 72 years of age. In agreement with these studies, Wolowczyk reported that fistula patency was substantially worse in women than in men [45].

Similarly, Gibson et al observed that the cumulative access survival (time from access placement to permanent failure) was better for fistulas than for grafts [35]. Once again, the differences were not uniform on subset analysis. Thus, fistulas outperformed grafts in white men and younger men, but were not clearly better in black men and older men. A recent European study observed a lower cumulative survival of fistulas as compared with grafts among patients aged 70 or older [46].

STRATEGIES TO INCREASE FISTULA PREVALENCE AMONG DIALYSIS PATIENTS

Taken together, the body of published literature suggests that the success rate of fistulas is not uniform among patient subgroups. When one considers all factors required for the long-term success of fistulas, including placement, successful maturation, and need for subsequent salvage procedures, the likelihood of success varies substantially among groups (Table 5). Specifically, the success rate of fistulas is less likely among women, blacks, and older patients. This suggests that even with optimal efforts to maximize the use of fistulas, the success rate among dialysis units may vary depending on patient characteristics. It is important to keep such differences in mind when comparing vascular access prevalence among dialysis units. For example, it is likely that units that dialyze men exclusively (such as Veterans Hospital-affiliated units) will have a higher than average proportion of patients with fistulas. In contrast, units with large black populations are likely to have a lower than average prevalence of fistulas. Notwithstanding these caveats, concerted and focused efforts should increase the prevalence of patients dialyzing with fistulas at any unit, regardless of the specific patient case-mix.

A multidisciplinary approach to vascular access

Multiple individuals are involved in the management of vascular access, including nephrologists, access surgeons, radiologists, dialysis nurses, and the patient. Achieving optimal vascular access outcomes requires agreement on a common set of goals by all these individuals, close collaboration, and good communication [10]. A key feature of a successful multidisciplinary approach to vascular access is having a dedicated access coordinator who acts as a liaison between all the services involved, schedules all access procedures, and maintains a computerized database. Prospective tracking of vascular access procedures and their complications is critical to evaluate whether changes in practice patterns result in improved outcomes. The multidisciplinary approach also can increase fistula placement in pre-dialysis patients by streamlining the referral process.

Rationale for preoperative vascular mapping

At most clinical centers, the surgeon decides what type of vascular access to place and at which anatomic location on the basis of physical examination alone, with and without a tourniquet. This type of approach may result in the use of inappropriate vessels for fistula construction, or conversely, failure to recognize a vessel suitable for fistula construction. Some patients may appear to have an excellent vein with a suitable caliber on inspection. However, sonographic evaluation may reveal an unsuspected stenosis or thrombosis in a more proximal portion of that vein, which would render that particular vein unsuitable for construction of a fistula. In other patients, physical examination may reveal no suitable veins for construction of a fistula. Sonographic evaluation, however, may reveal suitable veins that were simply too deep to appreciate clinically. Use of such veins may require venous transposition procedures to ensure that the fistula is superficial enough to be cannulated successfully for dialysis.

The caliber of the vessels used for fistula construction is an important factor predicting the likelihood of its maturation. For example, Malovrh reported that the patency rate of fistulas for dialysis at three months was just 36% if the preoperative internal diameter of the artery was <1.5 mm, but was 83% when this diameter was >1.5 mm [47]. Moreover, the flow rates in the fistula were higher in the second group, as compared with the first group. Similarly, Wong et al noted that if the artery or vein diameter was <1.5 mm, the fistula always failed to mature [48]. However, when the diameters were higher, it was not possible to predict on the basis of vessel diameter whether a given fistula would successfully mature. Similarly, we found that as long as the artery and vein met minimum diameter criteria (2 mm for the artery and 2.5 mm for the vein), there was no correlation between vessel diameter and likelihood of fistula maturation [13]. The mean artery and vein diameters during preoperative mapping are not significantly different between diabetic and non-diabetic patients. However, vascular calcifications are more frequent among diabetics than non-diabetics (64 vs. 35%) [43].

In one study preoperative vascular mapping limited the number of vessels and extremities available for vascular access placement in 66% (33 of 50) patients. Three-quarters of those patients had not had a previous vascular access. The most common abnormality observed was insufficient vein diameter [49]. We recently performed a pilot study to evaluate the impact of routine preoperative sonographic vascular mapping on the surgeon's choice of access [50]. Seventy consecutive patients scheduled for construction of a permanent vascular access were enrolled. The criteria for placement of a fistula were defined prospectively, and included a minimum artery diameter of 2 mm, a minimum vein diameter of 2.5 mm, and lack of stenosis or thrombosis in the draining vein or central veins [51]. The surgeon initially determined what type of vascular access to place and at which location, on the basis of a physical examination alone. Subsequently, the surgeon reviewed the results of the preoperative vascular mapping, and was asked whether those would change his intended surgical procedure. Preoperative ultrasound mapping resulted in a change in the planned surgical procedure in 31% of the patients. In most cases, the surgeon decided to place a fistula, rather than the planned graft, or to place the intended fistula at a different anatomic location [50].

Description of preoperative vascular mapping procedure

Vascular measurements are performed with the patient in a seated position, with their arm resting comfortably on a Mayo stand [50]. All measurements are in the anteroposterior dimension in the transverse plane. The minimum vein diameter for a native arteriovenous fistula is 0.25 cm. The minimum vein diameter for graft placement is 0.40 cm. The minimum arterial diameter for either fistula or graft placement is 0.20 cm. Veins are assessed for stenosis, thrombus and sclerosis (thickened walls).

First, the radial artery diameter at the wrist is measured. A tourniquet is then placed at the mid to upper forearm. The veins about the wrist are percussed for two minutes, with special emphasis on the cephalic vein area. Sequential measurements are made of the cephalic vein at the wrist, mid and cranial forearm. Any other dorsal or volar veins at the wrist also are measured and followed up the arm, according to established diameter criteria. The tourniquet is sequentially moved up the arm, and

Table 6. Effect of preoperative vascular mapping on vascular access outcomes

	% Fistulas placed		% Primary fistula failure		% Prevalence of fistula use	
Citation	Pre-VM	Post-VM	Pre-VM	Post-VM	Pre-VM	Post-VM
Silva, 1998 [51]	14	63	36	8	8	64
Ascher, 2000 [52]	0	100	N/A	18	5	68
Gibson, 2001 [35]	11	95	18	25	N/A	N/A
Allon, 2001 [13]	34	64	54	46	16	34
Sedlacek [43]	N/A	62	N/A	25	N/A	N/A
Mihmanli, 2001 [53]			25	6		
Miller, 1997 [34]	N/A	76				

Abbreviations are: VM, preoperative vascular mapping; N/A, not available.

cephalic, basilic, and brachial vein diameters are measured.

After the tourniquet is removed, the subclavian and jugular veins are assessed for stenosis and thrombus. Evidence of a more central stenosis is determined by analysis of the spectral Doppler waveform for respiratory phasicity and transmitted cardiac pulsatility.

Measurements are recorded on a worksheet. The sonographic measurements are used by the surgeon to select the most appropriate vascular access, on the basis of the following list agreed upon by our nephrologists, radiologists and vascular surgeons, from most desirable to least desirable:

1. Non-dominant forearm cephalic vein fistula
2. Dominant forearm cephalic vein fistula
3. Non-dominant, or dominant upper arm cephalic vein fistula
4. Non-dominant or dominant upper arm basilic vein transposition fistula
5. Forearm loop graft
6. Upper arm straight graft
7. Upper arm loop graft (axillary artery to axillary vein)

Effect of preoperative vascular mapping on vascular access outcomes

Four clinical studies have evaluated prospectively the effect of instituting preoperative vascular mapping on vascular access outcomes [13, 35, 51, 52]. In each case, using preoperative physical examination alone, only a small proportion of patients (0 to 34%) received a fistula, rather than a graft (Table 6). Following introduction of routine preoperative vascular mapping, the proportion of patients receiving fistulas increased to 63 to 100% (Table 6). Finally, a retrospective study reported that a combination of preoperative venography and intraoperative angioscopy resulted in fistula placement in 76% of patients [34]. The effect of such a program on the primary failure rate of fistulas constructed was inconsistent among studies. Whereas one study demonstrated a substantial decrease in the primary failure rate of fistulas [51], two other reports observed only slight increases or decreases in the primary failure rate (Table 6) [13, 35]. The net effect of preoperative vascular mapping was a consistent increase in the prevalence of patients successfully dialyzing with fistulas. In three studies only 5 to 16% of the patients were dialyzing with fistulas before implementation of routine preoperative vascular mapping; this proportion increased substantially (34 to 68% of patients) after introduction of such a program (Table 6). An additional study, which did not provide a historical control, reported that preoperative vascular mapping resulted in 62% of patients receiving a fistula, and a 25% primary failure rate [43]. Finally, a recent study from Turkey observed a reduction of the non-maturation rate of fistulas from 25 to 6% after implementing preoperative vascular mapping [53].

When preoperative vascular mapping is used to guide the surgeon, the inferior outcomes of forearm fistulas relative to upper arm fistulas were no longer observed. Prior to the use of preoperative mapping, the maturation rate at our center was 34% for forearm fistulas and 59% for upper arm fistulas [25]. With preoperative mapping, the respective maturation rates were 59 and 56%, respectively [13]. The improvement of forearm fistula adequacy was particularly striking among women (from 7 to 36%) and diabetic patients (from 21 to 50%). However, using these objective criteria, fistula placement was about one-third less likely in women than men, and about one-third less likely in black than white patients [13]. Thus, a fistula was possible in 92% of white males, but only 43% of black females. Similarly, Stehman-Breen et al reported that the first permanent vascular access placed was less likely to be a fistula in women, blacks, older patients, diabetics, and obese patients [24]. About 46% of fistulas placed with the benefit of preoperative vascular mapping at our center were in the upper arm, rather than the forearm. Fistula construction was more likely to be in the upper arm in women than men (64 vs. 36%), and more likely in blacks than whites (54 vs. 34%) [13]. Taken together, these observations suggest that women and black patients have smaller vessels.

Preoperative vascular information also can be obtained by venography. However, this approach suffers from several disadvantages. First, it evaluates just the veins, not the arteries. Second, there is a risk of inducing phlebitis, thereby jeopardizing the vein intended for fistula construction. Finally, among patients not yet on dialysis, exposure to radiocontrast dye may worsen the renal failure and precipitate an earlier requirement for dialysis. Digital subtraction venography with gadoterate meglumine may provide comparable information to standard venography without incurring the risk of nephrotoxicity, but is considerably more expensive than the use of nonionic iodinated contrast agents [54]. Despite its shortcomings, venography is more sensitive than ultrasound for detection of stenosis or thrombosis in the central veins, and may have a role in selected patients in whom there is a clinical suspicion for this problem. Sonography has, however, emerged as the method of choice for the preoperative assessment of the arteries and veins to assist the surgeon in planning vascular access placement.

Assessment of fistula maturation

In spite of the use of preoperative sonographic data to select vessels suitable for fistula construction, some fistulas still fail to mature adequately for dialysis use. There may be additional measurements obtained by preoperative Doppler ultrasound that predict clinically successful fistulas. These type of evaluations have not been addressed systematically, but may include a change in Doppler flow signal after fist clenching [47] or a preoperative subclavian venous flow rate >400 mL/min [55].

The expertise of dialysis nurses plays an important role in the assessment and successful cannulation of new fistulas. It is more technically challenging to cannulate fistulas as compared with grafts. Experienced dialysis nurses can successfully predict fistula maturation 80% of the time [37]. New dialysis nurses require considerable practice and supervision before they become adept at assessing and cannulating new fistulas. Given the much lower prevalence of fistulas among U.S. than European dialysis patients, U.S. dialysis nurses also have fewer opportunities to practice. Infiltration of new fistulas appears to occur more commonly with fistulas than grafts; when this occurs, there is a further delay in the successful use of a fistula for dialysis. Clearly, concerted efforts to enhance the proficiency of nurses in using fistulas for dialysis is a critical element in increasing the prevalence of patients dialyzing successfully with fistulas. During the present transition phase, when the prevalence of fistulas is increasing, it is extremely disappointing when a potentially functional fistula is compromised by laceration, infiltration, and serious hematoma at the time of its initial use. Perhaps formal certification of nurses for initial cannulation of fistulas should be considered. In no instance should the initial cannulation be delegated to a relatively inexperienced patient care technician.

Fistula maturation is usually evaluated by subjective physical examination by the dialysis nurse or nephrologist. We recently correlated objective postoperative sonographic measurements with clinical outcomes (adequacy for dialysis) of fistulas constructed after preoperative vascular mapping [37]. When the ultrasound revealed a minimum vein diameter >0.4 cm or a blood flow rate >500 mL/min, about 70% of the fistulas matured. If both criteria were met, the likelihood of fistula maturation was 95%; however, if neither criterion was achieved, the likelihood of fistula adequacy for dialysis was only 33%. Female patients were less likely than males to achieve the minimum vein diameter (40 vs. 69%). These observations suggest that veins in women may be less likely to dilate, thereby contributing to a 30% lower maturation rate, even when preoperative vascular mapping is used [13].

It would be helpful to identify the earliest time point at which subsequent maturation of a new fistula could be evaluated. This would result in either prompt intervention to salvage an immature fistula or in timely placement of a new vascular access, if the existing fistula is not likely to mature. An increase in blood flow occurs very early after fistula construction. In one prospective study, the mean arterial inflow on preoperative evaluation was 30 mL/min. Within 24 hours of surgery, the fistula blood flow was up to 472 mL/min, and by one week it had increased further to 861 mL/min [55]. A second prospective study observed a mean preoperative arterial inflow of 47 mL/min, which increased to 184 mL/min at one day, 202 mL/min at one week, 488 mL/min at eight weeks, and 562 mL/min at 12 weeks [47]. Retrospective analysis from our institution found that the blood flow was not significantly different in the second, third, or fourth month following fistula construction (707, 685, and 807 mL/min, respectively) [37]. Similarly, the minimum vein diameter was similar in the second, third, and fourth months after fistula placement (0.45, 0.46, and 0.39 cm, respectively) [37].

An early increase in access blood flow and vein diameter suggests that many fistulas could be cannulated successfully within a few weeks of their construction. However, in the United States the typical time interval from fistula placement to its successful use for dialysis is two to four months [12, 13, 26, 56]. New A-V fistulas are cannulated much earlier in Europe, as compared to the United States. Cannulation of fistulas within one month of their construction occurs 52% of the time in Europe, but only 2% of the time in the United States. Moreover, there is no association between the time of first cannulation and risk of fistula failure (abstract; Young et al, *J Am Soc Nephrol* 11:201A, 2000). The explanation for these striking practice differences among countries is not apparent. The shorter time to fistula cannulation in

Europe may contribute to the higher use of fistulas in Europe at initiation of dialysis, but would not account for the higher fistula use among prevalent dialysis patients.

Salvage of immature fistulas

Some fistulas fail to mature due to unrecognized stenosis in the draining vein, or large tributary veins that limit the blood flow through the main draining vein. An aggressive approach to evaluating immature fistulas for evidence of correctable abnormalities, with appropriate interventions, can improve the maturation rate. Beathard, Settle and Shields reported on their experience with 71 patients referred because of inadequate maturation of their fistulas [36]. Eight were not evaluated further because they were believed to have an inadequate arterial inflow. The remaining 63 patients underwent angioplasty of a stenotic lesion in the draining vein, ligation of one or more tributary veins, or a combination of both procedures. As a result of these salvage attempts 82.5% of the fistulas matured adequately to be used for dialysis.

In some cases surgical procedures may be helpful in salvaging a fistula. For example, in some obese patients, a postoperative ultrasound may reveal a well-developed fistula with an adequate diameter and blood flow that is simply too deep to be cannulated. A second surgical procedure to superficialize the fistula, by tunneling it subcutaneously, can render the fistula accessible to the dialysis nurse [13].

Salvage of clotted and stenosed A-V fistulas

Mature A-V fistulas are much less likely to clot than are grafts (Table 3). Unfortunately, when they do clot, thrombectomy is much more time-consuming and technically challenging for fistulas than grafts. Whereas declotting A-V grafts is a fairly standardized procedure, declotting a fistula requires considerable ingenuity and improvisation. Due to the low success rate of thrombectomy of fistulas, most U.S. centers have abandoned efforts at this procedure, and simply proceed with placement of a new vascular access once a fistula has clotted [11–13]. Some of the difficulties encountered in declotting fistulas include the thin venous wall, difficulty in localizing the anastomosis, the multiple possible locations of stenosis, the frequency of encountering very tight stenoses, the high frequency of venous aneurysms, and the large volume of clot [57]. Two groups of European investigators have recently reported good success rates in declotting A-V fistulas, using creative and meticulous radiologic techniques [57, 58]. The immediate technical success rate was about 90%, and the primary patency rate at six months was about 50% in both studies. The patency rate was much worse for upper arm fistulas than for forearm fistulas [57]. As the use of fistulas increases in the United States, it will be imperative that interventional radiologists and nephrologists become familiar and proficient with the methodology of fistula thrombectomy.

Although the frequency is lower than with grafts, fistulas also are prone to developing stenotic lesions [11]. Analogous to grafts, monitoring for hemodynamically significant stenosis and elective angioplasty can reduce the frequency of fistula thrombosis. A program of vascular access blood flow monitoring reduced the thrombosis rate of fistulas from 0.14 to 0.07 events per access-year at one center [11]. The primary patency following angioplasty is similar for fistulas and grafts [11, 59]. McCarley et al observed a median intervention-free survival after angioplasty of 161 days for fistulas and 148 days for grafts [11]. Similarly, Turmel-Rodrigues reported primary patency at six months after angioplasty to be 67% in fistulas, as compared with 53% in grafts [59].

DIFFERENCES BETWEEN VASCULAR ACCESS IN THE U.S. AND EUROPE

The ongoing Dialysis Outcomes and Practice Patterns Study (DOPPS) [17] has highlighted several significant differences in vascular access management in Europe, as compared with the United States. We have touched on some of these findings in various parts of this review. It will be important to explore these differences in the future, so as to increase the prevalence of fistula use in the U.S.

1. The use of fistulas is much more common in Europe than the United States, whether one looks at incident or prevalent patients [18]. Having more patients with fistulas gives European dialysis nurses more experience with cannulation of fistulas and the interventionalists more experience with fistula salvage and interventions.
2. Hemodialysis patients in Europe have lower comorbidity than do patients in the United States (Table 1) [18]. This difference may contribute, in part, to the higher prevalence of fistulas among European dialysis patients, but is unlikely to account by itself for the fourfold difference.
3. Fistulas in Europe are cannulated much earlier in Europe than in the United States (abstract; Young et al, *J Am Soc Nephrol* 11:201A, 2000). The reasons for this difference are not evident, but the presence of a large cadre of experienced dialysis nurses for initial cannulation may be a factor.
4. Mean dialysis blood flows are substantially lower in Europe than in the United States (mean flow, 300 vs. 412 mL/min; abstract; Dykstra et al, *J Am Soc Nephrol* 11:182A, 2000). Accepting lower dialysis blood flows may cause some fistulas to be considered useable in Europe, whereas they would be deemed inadequate in the United States.

5. European hemodialysis units have substantially higher staffing by registered nurses. Specifically, the ratio of registered nurse to patient dialysis-hour was 38% higher in Europe than in the United States (abstract; Mapes et al, *J Am Soc Nephrol* 12:337A, 2001). More experienced nurses are likely to have a higher success rate in cannulating fistulas.
6. Remarkably, hospitalization rates for vascular access problems are equally common in Europe and in the United States. Vascular access accounted for 25% of all hemodialysis patient hospitalizations in the United States and 24% of all hospitalizations in Europe (abstract: Young et al, *J Am Soc Nephrol* 10:259A, 1999). One would expect a lower rate of vascular access hospitalization in Europe, given the high prevalence of fistulas. However, a meaningful comparison is difficult due to the lack of information as to which procedures were for primary access placement, and which were done to salvage a failing or failed vascular access.

SUMMARY

Are the DOQI guidelines regarding fistulas achievable in the United States? The maximal achievable fistula prevalence is likely to vary among units, as a result of differences in gender, race, and co-morbidity mix. Nonetheless, adoption of specific measures outlined in this review, including a multidisciplinary approach to vascular access, early referral for vascular access, restriction of access procedures to surgeons with demonstrable interest and experience, routine preoperative vascular mapping, increased utilization of upper arm fistulas, enhanced training and certification of dialysis staff in fistula cannulation techniques, and efforts to salvage immature and thrombosed fistulas, will undoubtedly increase fistula prevalence in any hemodialysis unit.

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REFERENCES

1. Feldman HI, Kobrin S, Wasserstein A: Hemodialysis vascular access morbidity. *J Am Soc Nephrol* 7:523–535, 1996
2. Hakim R, Himmelfarb J: Hemodialysis access failure: A call to action. *Kidney Int* 54:1029–1040, 1998
3. NKF-DOQI clinical practice guidelines for vascular access. *Am J Kidney Dis* 37(Suppl 1):S150–S191, 1997
4. Port FK: Morbidity and mortality in dialysis patients. *Kidney Int* 46:1728–1737, 1994
5. Tokars JI, Miller ER, Alter MJ, Arduino MJ: National surveillance of dialysis-associated diseases in the United States, 1997. *Semin Dial* 13:75–85, 2000
6. Schwab SJ: Vascular access for hemodialysis. *Kidney Int* 55:2078–2090, 1999
7. Schwab SJ, Raymond JR, Saeed M, *et al*: Prevention of hemodialysis fistula thrombosis. Early detection of venous stenosis. *Kidney Int* 36:707–711, 1989
8. Besarab A, Sullivan KL, Ross RP, Moritz MJ: Utility of intra-access pressure monitoring in detecting and correcting venous outlet stenoses prior to thrombosis. *Kidney Int* 47:1364–1373, 1995
9. Safa AA, Valji K, Roberts AC, *et al*: Detection and treatment of dysfunctional hemodialysis access grafts: Effect of a surveillance program on graft patency and the incidence of thrombosis. *Radiology* 199:653–657, 1996
10. Allon M, Bailey R, Ballard R, *et al*: A multidisciplinary approach to hemodialysis access: Prospective evaluation. *Kidney Int* 53:473–479, 1998
11. McCarley P, Wingard RL, Shyr Y, *et al*: Vascular access blood flow monitoring reduces access morbidity and costs. *Kidney Int* 60:1164–1172, 2001
12. Oliver MJ, McCann RL, Indridason OS, *et al*: Comparison of transposed brachiobasilic fistulas to upper arm grafts and brachiocephalic fistulas. *Kidney Int* 60:1532–1539, 2001
13. Allon M, Lockhart ME, Lilly RZ, *et al*: Effect of preoperative sonographic mapping on vascular access outcomes in hemodialysis patients. *Kidney Int* 60:2013–2020, 2001
14. Hirth RA, Turenne MN, Woods JD, *et al*: Predictors of type of vascular access in hemodialysis patients. *JAMA* 276:1303–1307, 1996
15. Allon M, Ornt D, Schwab S, *et al*: Factors associated with the prevalence of A-V fistulas in hemodialysis patients in the HEMO Study. *Kidney Int* 58:2178–2185, 2000
16. HCFA: Health Care Financing Administration: *2000 Annual Report, End Stage Renal Disease Clinical Performances Measures Project*. Baltimore, Department of Health and Human Services, Health Care Financing Administration, Office of Clinical Standards and Quality, 2000
17. Young EW, Goodkin DA, Mapes DL, *et al*: The Dialysis Outcomes and Practice Patterns Study (DOPPS): An international hemodialysis study. *Kidney Int* 57(Suppl 74):S74–S81, 2000
18. Pisoni RL, Young EW, Dykstra DM, *et al*: Vascular access use in Europe and in the United states: Results from the DOPPS. *Kidney Int* 61:305–316, 2002
19. Goodkin DA, Chen K, Held PJ, *et al*: Factors influencing type of permanent vascular access at start of hemodialysis. *Proc Eighth Annu Clin Nephrol Meetings* 8:187–188, 1999
20. Coburn MC, Carney WI: Comparison of basilic vein and polytetrafluoroethylene for brachial arteriovenous fistula. *J Vasc Surg* 20:896–904, 1994
21. Kherlakian GM, Roedersheimer LR, Arbaugh JJ, *et al*: Comparison of autogenous fistula versus expanded polytetrafluoroethylene graft fistula for angioaccess in hemodialysis. *Am J Surg* 152:238–243, 1986
22. Ifudu O, Macey LJ, Homel P, *et al*: Determinants of type of initial hemodialysis vascular access. *Am J Nephrol* 17:425–427, 1997
23. Rocco MV, Bleyer AJ, Burkart JM: Utilization of inpatient and outpatient resources for the management of hemodialysis access complications. *Am J Kidney Dis* 28:250–256, 1996
24. Stehman-Breen CO, Sherrard DJ, Gillen D, Caps M: Determinants of type and timing of initial permanent hemodialysis vascular access. *Kidney Int* 57:639–645, 2000
25. Miller PE, Tolwani A, Luscy CP, *et al*: Predictors of adequacy of arteriovenous fistulas in hemodialysis patients. *Kidney Int* 56:275–280, 1999
26. Dixon BS, Novak l, Fangman J: Hemodialysis vascular access survival: the upper arm native arteriovenous fistula. *Am J Kidney Dis* 39:92–101, 2002
27. Schwab SJ, Beathard GA: The hemodialysis catheter conundrum: Hate living with them, but can't live without them. *Kidney Int* 56:1–17, 1999
28. Arora P, Obrador Gt, Ruthazer R, *et al*: Prevalence, predictors, and consequences of late nephrology referral at a tertiary care center. *J Am Soc Nephrol* 10:1281–1286, 1999

29. Astor BC, Eustace JA, Powe NR, *et al*: Timing of nephrologist referral and arteriovenous access use: The CHOICE Study. *Am J Kidney Dis* 38:494–501, 2001
30. Roubicek C, Brunet P, Huiart L, *et al*: Timing of nephrology referral: Influence on mortality and morbidity. *Am J Kidney Dis* 36:35–41, 2000
31. Brescia MJ, Cimino JE, Appel K, Hurwick BF: Chronic hemodialysis using venipuncture and a surgically created arteriovenous shunt. *N Engl J Med* 275:1089–1092, 1966
32. Dagher F, Gelber R, Ramos E, Sadler J: The use of basilic vein and brachial artery as an A-V fistula for long term hemodialysis. *J Surg Res* 20:373–376, 1976
33. Polo JR, Vazquez R, Polo J, *et al*: Brachiocephalic jump graft fistula: an alternative for dialysis use of elbow crease veins. *Am J Kidney Dis* 33:904–909, 1999
34. Miller A, Holzenbein TJ, Gottlieb MN, *et al*: Strategies to increase the use of autogenous arteriovenous fistula in end-stage renal disease. *Ann Vasc Surg* 11:397–405, 1997
35. Gibson KD, Caps MT, Kohler TR, *et al*: Assessment of a policy to reduce placement of prosthetic hemodialysis access. *Kidney Int* 59:2335–2345, 2001
36. Beathard GA, Settle SM, Shields MW: Salvage of the nonfunctioning arteriovenous fistula. *Am J Kidney Dis* 33:910–916, 1999
37. Robbin ML, Chamberlain NE, Lockhart ME, *et al*: Sonographic evaluation of hemodialysis arteriovenous fistula maturity. *Radiology* (in press)
38. Hakaim AG, Nalbandian M, Scott T: Superior maturation and patency of primary brachiocephalic and transposed basilic vein arteriovenous fistulae in patients with diabetes. *J Vasc Surg* 27:154–157, 1998
39. Bender MHM, Bruyninckx MA, Gerlag PGG: The brachiocephalic elbow fistula: A useful alternative angioaccess for permanent hemodialysis. *J Vasc Surg* 20:808–813, 1994
40. Sands J, Miranda C: Optimizing hemodialysis access: A teaching tool. *Nephrol News Issues* 10:16–27, 1996
41. Kaufman JS: Antithrombotic agents and the prevention of access thrombosis. *Semin Dial* 13:40–46, 2000
42. Rodriguez MM, Almazan EA, Ramos BM, *et al*: Hand exercise effect in maturation and blood flow of dialysis arteriovenous fistulas ultrasound study. *Angiology* 35:641–644, 1984
43. Sedlacek M, Teodorescu V, Falk A, *et al*: Hemodialysis access placement with preoperative noninvasive vascular mapping: Comparison between patients with and without diabetes. *Am J Kidney Dis* 38:560–564, 2001
44. Astor BC, Coresh J, Powe NR, *et al*: Relation between gender and vascular access complications in hemodialysis patients. *Am J Kidney Dis* 36:1126–1134, 2000
45. Wolowczyk L, Williams AJ, Donovan Kl, Gibbons CP: The snuffbox arteriovenous fistula for vascular access. *Eur J Vasc Endovasc Surg* 19:70–76, 2000
46. Staramos DN, Lazarides MK, Tzilalis VD, *et al*: Patency of autologous and prosthetic arteriovenous fistulas in elderly patients. *Eur J Surg* 166:777–781, 2000
47. Malovrh M: Non-invasive evaluation of vessels by duplex sonography prior to construction of arteriovenous fistulas for hemodialysis. *Nephrol Dial Transplant* 13:125–129, 1998
48. Wong V, Ward R, Taylor J, *et al*: Factors associated with early failure of arteriovenous fistulae for hemodialysis access. *Eur J Vasc Endovasc Surg* 12:207–213, 1996
49. Comeaux ME, Bryant PS, Harkrider WW: Preoperative evaluation of the renal access patient with color Doppler imaging. *J Vasc Technol* 17:247–250, 1993
50. Robbin ML, Gallichio ML, Deierhoi MH, *et al*: US vascular mapping before hemodialysis access placement. *Radiology* 217:83–88, 2000
51. Silva MB, Hobson RW, Pappas PJ, *et al*: A strategy for increasing use of autogenous hemodialysis access procedures: Impact of preoperative noninvasive evaluation. *J Vasc Surg* 27:302–308, 1998
52. Ascher E, Gade P, Hingorani A, *et al*: Changes in the practice of angioaccess surgery: Impact of dialysis outcomes quality initiative recommendations. *J Vasc Surg* 31:84–92, 2000
53. Mihmanli I, Besirli K, Kurugoglu S, *et al*: Cephalic vein and hemodialysis fistula: Surgeon's observation versus color Doppler ultrasonographic findings. *J Ultrasound Med* 20:217–222, 2001
54. Geoffroy O, Tassart M, Le Blanche AF, *et al*: Upper extremity digital subtraction venography with gadoterate meglumine before fistula creation for hemodialysis. *Kidney Int* 59:1491–1497, 2001
55. Yerdel MA, Kesenci M, Yazicioglu KM, *et al*: Effect of haemodynamic variables on surgically created arteriovenous fistula flow. *Nephrol Dial Transplant* 12:1684–1688, 1997
56. Miller PE, Carlton D, Deierhoi MH, *et al*: Natural history of arteriovenous grafts in hemodialysis patients. *Am J Kidney Dis* 36:68–74, 2000
57. Turmel-Rodrigues L, Pengloan J, Rodrigue H, *et al*: Treatment of failed native arteriovenous fistulae for hemodialysis by interventional radiology. *Kidney Int* 57:1124–1140, 2000
58. Haage P, Vorwerk D, Wilberger JE, *et al*: Percutaneous treatment of thrombosed primary arteriovenous hemodialysis access fistulae. *Kidney Int* 57:1169–1175, 2000
59. Turmel-Rodrigues L, Pengloan J, Baudin S, *et al*: Treatment of stenosis and thrombosis in haemodialysis fistulas and grafts by interventional radiology. *Nephrol Dial Transplant* 15:2029–2036, 2000
60. Levinsky NG: The organization of medical care: Lessons from the Medicare End-Stage Renal Disease Program. *N Engl J Med* 329: 1395–1399, 1993
61. Rostand SG, Gretes JC, Kirk KA, *et al*: Ischemic heart disease in patients with uremia undergoing maintenance hemodialysis. *Kidney Int* 16:600–611, 1979
62. Kinnaert P, Vereerstraeten P, Toussaint C, Van Geertruyden J: Nine years' experience with internal arteriovenous fistulas for haemodialysis: A study of some factors influencing the results. *Br J Surg* 64:242–246, 1977
63. Bonalumi U, Civalleri D, Rovida S, *et al*: Nine years' experience with end-to-end arteriovenous fistula at the "anatomic snuffbox" for maintenance hemodialysis. *Br J Surg* 69:486–488, 1982
64. Reilly DT, Wood RFM, Bell PRF: Prospective study of dialysis fistulas: Problem patients and their treatment. *Br J Surg* 69:549–553, 1982
65. Palder SB, Kirkman RL, Whittemore AD, *et al*: Vascular access for hemodialysis: Patency rates and results of revisions. *Ann Surg* 202:235–239, 1985
66. Winsett OE, Wolma FJ: Complications of vascular access for hemodialysis. *South Med J* 78:513–517, 1985
67. Churchill DN, Taylor DW, Cook RJ, *et al*: Canadian hemodialysis morbidity study. *Am J Kidney Dis* 19:214–234, 1992
68. Hodges TC, Fillinger MF, Zwolak RM, *et al*: Longitudinal comparison of dialysis access methods: Risk factors for failure. *J Vasc Surg* 26:1009–1019, 1997
69. Golledge J, Smith CJ, Emery J, *et al*: Outcome of primary radiocephalic fistula for haemodialysis. *Br J Surg* 86:211–216, 1999
70. Konner K: Primary vascular access in diabetic patients: an audit. *Nephrol Dial Transplant* 15:1317–1325, 2000
71. Murphy GJ, White SA, Nicholson ML: Vascular access for haemodialysis. *Br J Surg* 87:1300–1315, 2000
72. Revanur VK, Jardine AG, Hamilton DH, Jindal RM: Outcome for arterio-venous fistula at the elbow for haemodialysis. *Clin Transplant* 14:318–322, 2000