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Static intra-access pressure ratio does not correlate with access blood flow

Rapid Communication

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Static intra-access pressure ratio does not correlate with access blood flow.

Background. Access flow (Qa) measurement is recommended by Kidney Disease Outcomes Quality Initiative (K/DOQI) as the preferred method for access surveillance. Static intra-access pressure ratio (SIAPR) measurement is the second surveillance method of choice. The purpose of this prospective multicenter study was to investigate the relationship between SIAPR and Qa and to examine the premise upon which SIAPR surveillance is based—namely, that high SIAPR is a surrogate for low Qa associated with hemodynamically significant stenosis.

Methods. SIAPR and Qa (HD01; Transonic Systems, Inc., Ithaca, NY, USA) were simultaneously measured monthly in 242 patients [146 prosthetic arteriovenous bridge grafts (AVG), 96 autogenous arteriovenous fistulas (AVF)] from three centers. SIAPR was measured according to the K/DOQI protocol.

Results. There was no correlation between Qa and venous or arterial SIAPR in AVGs (R^2 = 0.0037 and R^2 = 0.006, respectively, N = 730), or in AVFs (R^2 = 0.0247 and R^2 = 0.0329, respectively, N = 431). Of the high SIAPR measurements in AVGs, 81% and 50% were associated with Qa $\geq$600 and Qa $\geq$1000 mL/min, respectively. Of the AVGs studied, 41% (60/146) had consistently high Qa $\geq$1000 mL/min. Seventy percent (42/60) of these high-Qa AVGs had at least two consecutive sessions with high SIAPR measurements, thereby meeting the K/DOQI SIAPR criteria for referral. In addition, 78% (14/18) of new AVGs with Qa $\geq$1000 mL/min, and 86% (6/7) of AVGs with the highest Qa ($\geq$2000 mL/min), had high SIAPR. As a result, these high-Qa AVGs, which represented the best functioning AVGs by K/DOQI Qa standards, were erroneously targeted for referral based on SIAPR measurements.

Conclusion. SIAPR does not correlate with Qa or discriminate between high and low Qa. Therefore, because the utility of SIAPR surveillance for detection of clinically significant stenosis depends on a correlation with Qa, the current use of absolute K/DOQI SIAPR thresholds for intervention based on the presumption that such thresholds are indicative of low Qa is not justified, and should be discontinued. Studies need to be done to examine the utility of SIAPR for trend analysis.

Key words: static intra-access pressure ratio, access blood flow, access surveillance.

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The National Kidney Foundation (NKF) Kidney Disease Outcomes Quality Initiative (K/DOQI) Guidelines recommends intra-access flow (Qa) measurement as the preferred vascular access surveillance method, followed by static intra-access pressure ratio (SIAPR), which is static intra-access pressure normalized to mean arterial pressure (MAP) [1]. The K/DOQI SIAPR protocol includes referral of a patient with two consecutive abnormal SIAPR measurements, based on K/DOQI-designated absolute thresholds [1]. The SIAPR surveillance method is based on the theoretical premise [2, 3] that intra-access pressure is a surrogate for Qa (i.e., that high SIAPR correlates with low Qa associated with hemodynamically significant outflow stenosis). Despite the wide availability of SIAPR and Qa measurements during hemodialysis over the past 8 to 10 years, we could not find a published study directly comparing these methods that established a correlation between SIAPR and Qa. The purpose of this prospective, multicenter study was to investigate the relationship between SIAPR and Qa, and to examine the premise that K/DOQI-designated abnormal SIAPR thresholds are indicative of low Qa.

METHODS

The study period was from January through August, 2002, and included 242 patients [146 prosthetic arteriovenous bridge grafts (AVG), 96 autogenous arteriovenous fistulas (AVF)] from three DaVita Houston Kidney Centers (HKC), Texas: (*1*) HKC North (126 patients: 84 AVG, 42 AVF); (2) HKC Northwest (65 patients: 35 AVG, 30 AVF); and (3) HKC Southeast (51 patients: 27 AVG, 24 AVF). All patients who gave consent were included in the study. SIAPR and Qa were simultaneously measured monthly, for a total of 1161 measurement sessions (730

Table 1. Graft Qa versus normal and abnormal SIAPR (by K/DOQI SIAPR threshold criteria)

	Access flow (Qa) (mL/min)			
SIAPR	Center 1 $N = 518$	Center 2 $N = 78$	Center 3 $N = 134$	Total
Normal	890 ± 413	1480 ± 396	1002 ± 383	946 ± 433
Abnormal	892 ± 400	1371 ± 335	1376 ± 696[a]	1067 ± 527[a]

Abnormal SIAPR in AVG according to K/DOQI included: venous SIAPR ≥0.5 and/or arterial SIAPR ≥0.75 and/or arterial SIAPR <0.3; N = number of measurements.
[a] $P \leq 0.05$ is statistically significant.

AVG, 431 AVF) during the 8-month study period (average 4.8/patient).

Access flow (Qa)

Qa was measured by HD01 (Transonic Systems, Inc., Ithaca, NY, USA) [4]. Measurements were performed during the first 1.5 hours of the hemodialysis session according to the K/DOQI protocol. Measurements were performed in duplicate, and if the two measurements differed by more than 10%, a third measurement was taken and the two closest were averaged.

Static intra-access pressure ratio (SIAPR)

SIAPR, both venous and arterial, were measured on Fresenius 2008H machines (machine) (Fresenius Medical Care NA, Lexington, MA, USA), on which the pressure transducers were zeroed at atmospheric pressure prior to connection with the dialysis blood circuit. SIAPR measurements and calculations were made according to the K/DOQI protocol (calculation A) [1] to eliminate the influence of the height between the needle and drip chamber, as well as MAP. In addition, SIAPR was also measured at centers 2 and 3 using the Access Alert device (Medisystems, Inc., Seattle, WA, USA). This device consists of a cannulation needle and tubing attached to a sterile hydrophobic filter, which, when connected to a manometer, permits direct measurement of access pressure at the time of access cannulation. All results are presented as mean values ± standard deviation unless otherwise specified.

RESULTS

Correlations

There was no correlation between Qa and venous or arterial SIAPR in AVGs ($R^2 = 0.0037$ and $R^2 = 0.006$, respectively, $N = 730$), or in AVFs ($R^2 = 0.0247$ and $R^2 = 0.0329$, respectively, $N = 431$). Because K/DOQI underscores the limited utility of pressure (static and dynamic) surveillance in AVFs, but recommends SIAPR as a preferred surveillance method for AVGs [1], additional analysis was directed to the AVG group.

AVGs with abnormal SIAPR

Table 1 shows that AVGs in the study with abnormal SIAPR (according to K/DOQI criteria) had higher

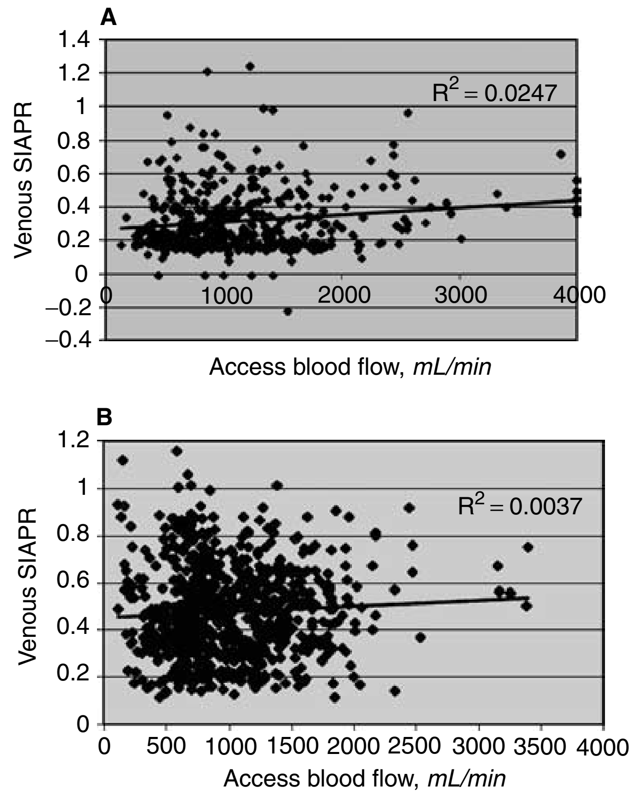

Fig. 1. Access flow (Qa) versus venous static intra-access pressure ratio (SIAPR) in native fistulas (*A*) and in grafts (*B*).

Qa than AVGs with normal SIAPR. Among the 394 AVG measurement sessions with high SIAPR (venous ≥0.5 and/or arterial ≥0.75), 81% were associated with Qa ≥600 mL/min and 50% were associated with Qa ≥1000 mL/min (see Fig. 1B).

High-Qa AVGs

Of the AVGs studied, 41% (60/146) had consistently high Qa ≥1000 mL/min (high-Qa group). In this high-Qa group, 70% (42/60) of the patients had at least two consecutive sessions with high SIAPR, thereby meeting the K/DOQI SIAPR criteria for referral for presumed significant outflow stenosis. Of the seven AVG with the highest Qa (≥2000 mL/min), 86% (6/7) consistently demonstrated high SIAPR and also met the K/DOQI SIAPR criteria for referral. There was no significant difference in

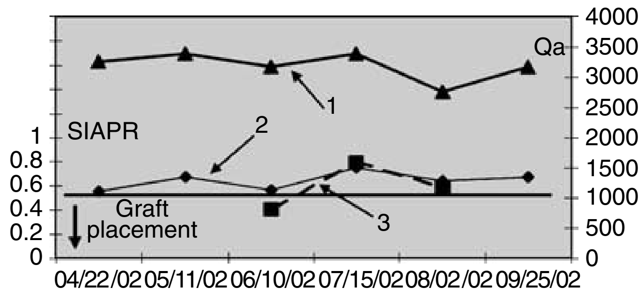

Fig. 2. Example of patient with high-Qa graft (denoted by 1) and consistently high venous static intra-access pressure ratio (SIAPR) measured from the hemodialysis machine (denoted by 2) and directly by "Access Alert" (denoted by 3).

distribution of the high-SIAPR/high-Qa AVGs between the forearm loop and upper arm positions. However, of the six thigh AVGs with high Qa, 83% (5/6) had consistently high SIAPR, including the one new AVG.

New AVGs

During the study period, 24 new AVGs were placed. 18/24 (75%) had consistent Qa $\geq$1000 mL/min, of which 14/18 (78%) patients had at least two consecutive dialysis sessions with high SIAPR, thereby meeting the K/DOQI criteria for referral. An example of a new high-Qa/high-SIAPR AVG is depicted in Figure 2.

Access alert versus machine measurements

In 200 measurement sessions, 400 measurements (200 arterial, 200 venous) were performed by both Access Alert and machine. In 77%, there was diagnostic agreement between Access Alert and machine measurements.

DISCUSSION

The purpose of access surveillance is to identify accesses at risk for failure and specifically, to detect hemodynamically significant stenoses. Qa directly represents access function, and K/DOQI recommends Qa measurement as the preferred surveillance method, followed by SIAPR measurement. The SIAPR method is based on the presumption that high SIAPR is an indirect indicator of low Qa associated with hemodynamically significant stenosis [2, 3], and the value and utility of SIAPR for surveillance is therefore dependent on such a relationship existing between SIAPR and Qa. In fact, a number of studies have suggested that no correlation exists between SIAPR and Qa [5–10], while others suggest that this relationship does exist [2, 3, 11, 12]. We could not find a published mathematical or theoretical basis for a correlation or surrogate relationship between SIAPR and Qa. To our knowledge, this is the first prospective, multicenter study to examine the relationship between SIAPR and Qa, with analysis of the clinical implications based on the K/DOQI surveillance guidelines.

The results (Table 1, Figs. 1 and 2) indicate definitively that there is no correlation between SIAPR and Qa, and further, that SIAPR at any level cannot discriminate between high and low Qa. In fact, this study shows that, in direct contrast to the premise that high SIAPR is associated with low Qa related to outflow stenosis, high SIAPR is as likely to be present in high-Qa AVGs and new AVGs. These findings were confirmed with the Access Alert device (see Fig. 2). The study findings can be explained by the following mathematical model.

Mathematical model for venous static intra-access pressure ratio (SIAPR) measurement

Access flow (Qa) can be calculated as follows (for simplicity, central venous pressure is excluded because it is considered to be minor relative to MAP):

$$\mathrm{Qa} \approx \mathrm{MAP}/(\mathrm{Rout} + \mathrm{Rin}) \quad \text{(Equation 1)}$$

where R (in) = inflow resistance upstream of venous needle (arterial segment of access, arterial anastomosis, feeding artery, arterial tree to heart); R (out) = outflow resistance downstream of venous needle (venous segment of access, venous anastomosis, venous outflow to heart); and MAP = mean arterial pressure.

Static intra-access pressure ratio (SIAPR) is:

$$\mathrm{SIAPR} \approx \mathrm{Qa} \times \mathrm{Rout}/\mathrm{MAP} \quad \text{(Equation 2)}$$

which can also be expressed as:

$$\mathrm{SIAPR} \approx \mathrm{Rout}/(\mathrm{Rout} + \mathrm{Rin}) \quad \text{(Equation 3)}$$

Equation 3 shows that SIAPR only indicates the relative relationship of outflow resistance to total resistance, and is unrelated to Qa. Thus, for example, an observed venous SIAPR $\geq$0.5, which is the K/DOQI AVG threshold for referral, is simply an indication that the outflow represents 50% of total resistance—and not a measure of Qa or function, or an indicator of the absence or presence of a clinically significant outflow stenosis. This mathematical model explains why a given SIAPR cannot be designated as being abnormal and established as a threshold to indicate low Qa or clinically significant outflow stenosis, thereby refuting the basis of existing SIAPR guidelines [1–3]. This is also true for native AVF accesses and for dynamic pressure measurements. High SIAPR can be due to either high outflow resistance (i.e., outflow stenosis), associated with low Qa and dysfunction, or low resistance to arterial inflow (related to a large/healthy feeding artery, anastomosis, and arterial segment of access), associated with *high* Qa and excellent function. SIAPR measurement cannot discriminate between these two causes of high pressure, since the SIAPR method does not account for the significant arterial inflow contribution to

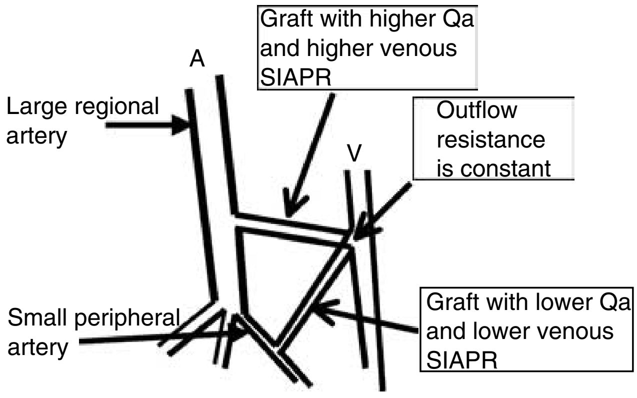

Fig. 3. Schematic of graft connected to large versus small feeding artery with the same venous anastomosis.

total access resistance. Figure 3 explains the finding of high Qa with high SIAPR. The venous anastomosis in both cases is the same, R(out) is constant (Equation 2), but R(in) is lower in the case with the larger feeding artery (Equation 3), causing SIAPR to be higher as a result of the increase in Qa.

Clinical implications

This lack of correlation between flow and pressure, illustrated by the above mathematical model, explains the results of this study (Figs. 1 and 2, Table 1), as well as a number of studies that have reported pressure surveillance to be ineffective or to be lacking predictive accuracy [9, 10, 13, 14]. Study findings supporting an association of high SIAPR with stenosis [15] or a reduction in thrombosis rates [8], are not a contradiction to the findings or conclusions in this study. Because, with few exceptions, all AVGs develop stenosis, any criteria or basis used for referral will result in the identification of stenosis, and potentially to a reduction in thrombosis. In fact, the authors recognize and acknowledge that SIAPR can identify a subset of AVGs with outflow stenosis because outflow stenosis is one cause of high SIAPR. However, a surveillance tool must have sufficient discriminatory power to minimize false-positive referrals. This study shows that SIAPR at any threshold cannot discriminate between an access with clinically significant stenosis and a well-functioning access with high Qa. Therefore, although the use of absolute SIAPR thresholds can be expected to identify a proportion of AVG patients with outflow stenosis, based on the study findings, this is accomplished at the cost of erroneously targeting a high proportion of patients with well-functioning accesses, thus potentially leading to excessive, unnecessary, and costly interventions. These high-SIAPR accesses with high Qa represent false-positive SIAPR referrals because, based on the K/DOQI-preferred Qa surveillance criteria, these accesses should not be referred.

Trend analysis versus absolute SIAPR thresholds

The K/DOQI SIAPR protocol uses referral criteria based on trend analysis, as well as absolute SIAPR thresholds. We could not find a clinical study supporting the utility and effectiveness of SIAPR trend analysis or specifically, the K/DOQI-recommended SIAPR trending threshold for referral of >0.25 over baseline. Although investigation of trend analysis was not within the scope of this study, the study findings raise serious concerns as to the potential clinical utility of trend analysis based on current guidelines. Certainly, an upward trend of SIAPR from an established baseline will indicate outflow stenosis, assuming R(in) remains constant as R(out) increases due to progression of outflow stenosis. However, as observed in this study, SIAPR at any designated threshold does not correlate with Qa, and an access can have any Qa at any given SIAPR. In other words, an access with an SIAPR that has gradually increased to the trending threshold for referral of >0.25 from baseline, could have a Qa of 2400 mL/min or 600 mL/min or any Qa—which would not be known using SIAPR surveillance alone. Therefore, without knowledge of the baseline Qa or the ability to quantify Qa at any given SIAPR, it is unlikely that trend analysis, using pressure (static or dynamic) alone, can be used to determine the appropriate timing for intervention, which is critical in order to avoid excessive unnecessary and costly interventions [2]. In an attempt to avoid excessive referrals using SIAPR surveillance, and to minimize costs and staff time, a hybrid model combining SIAPR and Qa surveillance protocols has been recommended [2, 11]. However, if a Qa measurement tool is not available, another option would be to wait for an upward trend in SIAPR, and then attempt to confirm dysfunction by physical examination of the access or another noninvasive study—before referring the patient for invasive diagnostic evaluation and intervention.

CONCLUSION

The results of this study indicate that SIAPR does not correlate with Qa, or discriminate between high and low Qa. Therefore, an absolute SIAPR at any level cannot be used as a surrogate for low Qa or access dysfunction. In fact, the majority of high SIAPR measurements were in accesses with high Qa, including new AVGs. Thus, although the SIAPR method may detect outflow stenoses, it is as likely to erroneously target high-Qa, well-functioning accesses for referral, which may lead to intervention for the best-functioning accesses. Therefore, the current use of absolute K/DOQI SIAPR thresholds for referral based on the presumption that such thresholds are indicative of low Qa associated with stenosis is not justified and should be discontinued. Further studies are required to determine if effective trending guidelines can be identified to establish the utility of SIAPR trend analysis for access surveillance. Based on the study findings, the K/DOQI surveillance guidelines should be re-evaluated and revised.

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