Measurement of vascular access blood flow rate during hemodialysis in 38 patients using the thermodilution technique. A comparative study with the Delta-H method

R. Roca-Tey, R. Samon, O. Ibrik, I. Giménez and J. Viladoms

Servicio de Nefrología. Fundación Privada Hospital de Mollet. Barcelona.

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SUMMARY

Introduction: *Periodic QA measurement is the preferred way for vascular access (VA) surveillance in end-stage renal disease (ESRD) patients (pts).*

Objective: *The aims of this study were to measure QA by TDT and to compare the functional results with Delta-H method.*

Patients and methods: *We measured Q_A non invasively in 38 VA (mean VA duration: 48.7 ± 69,8 months) during HD in 38 stable ESRD (mean age 63.8 ± 15.1 yr, mean time on HD 47.6 ± 53.9 months, diabetic nephropathy 18.4%) pts by the TDT. Fourteen pts (36.8%) had history of previous VA that were ipsilateral to the VA under study in most cases (11/14, 78.6%). Thirteen pts (34.2%) had history of any comorbidity other than diabetes mellitus (coronary artery or cerebrovascular or peripheral vascular diseases). Q_A was calculated from the recirculation values obtained by means of the blood temperature monitor (BTM), integrated into the Fresenius Medical Care 4008-S machine, at normal and reverse configurations of the HD blood lines. Q_A was measured within the first hour of two consecutive HD sessions (the values were averaged). Mean arterial pressure MAP and distance between needles (DBN) were measured simultaneous with Q_A. In addition, the VA blood flow was also determined by Delta-H method using Crit-Line III Monitor (ABF-mode, HemaMetrics, USA).*

Results: *Mean Q_A was 1170.5 ± 464.2 ml/min (range, 289.4-2,346,4 ml/min). Most VA (44.7%) showed mean Q_A between 1,000 and 1,500 ml/min. The mean DBN and MAP were 6.2 ± 2.9 cm, 91.9 ± 12.4 mmHg, respectively. Mean Q_A was similar for pts with mean MAP < 100 mmHg (n = 26) and for pts with mean MAP ≥ 100 mmHg (n = 12) (p = 0.85). Pts with diabetic nephropathy showed lower mean Q_A (836.1 ± 395.8 ml/min) compared to the remaining pts (1,245.9 ± 449.9 ml/min) (p = 0.033). No differences in mean Q_A was found when pts with any comorbidity and without comorbidities were compared (p = 0.62). Brachial AVF tended to have higher mean Q_A (1,323.6 ± 465.3 ml/min) compared to radial AVF (1,017.4 ± 447.3 ml/min) (p = 0.052). Pts with history of previous VA showed higher mean Q_A (1,410.6 ± 377.7 ml/min) compared to the remaining pts (1,030.4 ± 458.7 ml/min) (p = 0.013). No correlation was found between mean Q_A and: mean age, DBN, MAP, Kt/V index, time on HD and VA duration. Mean Q_A obtained by TDT was not different when compared with mean ABF determined by Delta-H method (1,151.3 ± 479.0 ml/min) (p = 0.89). The calculated values of VA blood flow obtained by TDT were highly correlated with those determined by the Delta-H method (intraclass correlation coefficient = 0.95, p < 0.001).*

Conclusions: *The TDT is an indicator of QA during HD. The functional profile of VA was worse in pts with diabetic nephropathy or without history of previous VA. The VA blood flow values obtained by TDT and Delta-H techniques correlated highly with each other.*

Key words: Vascular access. Blood flow rate. Thermodilution. Delta-H.

RESUMEN

Introducción: **La determinación periódica del flujo sanguíneo (QA) del acceso vascular (AV) es el método de elección para su monitorización en los pacientes (pts) con IRC.**

Objetivos: **Determinar QA mediante la técnica de Termodilución (TDT) y comparar los resultados funcionales con el método Delta-H.**

Pacientes y método: **Hemos determinado no invasivamente el Q_A de 38 AV (duración media 48,7 ± 69,8 meses) durante la HD en 38 pts (edad media 63,8 ± 15,1 años, tiempo medio en HD 47,6 ± 53,9 meses, nefropatía diabética 18,4%) con IRC mediante TDT. Catorce pts (36,8%) tenían el antecedente de algún AV previo, que fue ipsilateral al AV actual en la mayoría de los casos (11/14, 78,6%). Trece pts (34,2%) tenían el antecedente de alguna comorbilidad distinta de la diabetes (cardiopatía isquémica o enfermedad cerebrovascular o arteriopatía periférica). El Q_A se calculó a partir de los valores de recirculación obtenidos mediante el monitor de temperatura sanguínea (BTM), integrado en la máquina Fresenius Medical Care 4008-S, con las líneas sanguíneas de HD en configuración normal e invertida. El Q_A se determinó durante la primera hora de 2 sesiones consecutivas de HD (ambos valores se promediaron). La presión arterial media PAM y la distancia entre las agujas (DEA) se registraron simultáneamente con Q_A. Además, el flujo sanguíneo del AV se determinó nuevamente en un plazo no superior a 15 días mediante el método Delta-H utilizando el monitor Crit Line III (HemaMetrics, USA).**

Resultados: **El Q_A medio fue 1.170,5 ± 464,2 ml/min (intervalo, 289,4-2.346,4 ml/min). La mayoría de AV (44,7%) presen-**

Correspondence: *Ramón Roca-Tey*
Tamarit, 144-146, 3.º 3.ª
08015 Barcelona
18647rrt@comb.es

taban un Q_A medio comprendido entre 1.000 y 1.500 ml/min. La DEA y PAM medios fueron 6,2 ± 2,9 cm y 91,9 ± 12,4 mmHg, respectivamente. El Q_A fue similar tanto para los pts con PAM inferior a 100 mmHg (n = 26) como para los pts con PAM igual o superior a 100 mmHg (n = 12) (p = 0,85). Los pts con nefropatía diabética presentaron un QA significativamente inferior (836,1 ± 395,8 ml/min) en relación a los restantes pts (1.245,9 ± 449,9 ml/min) (p = 0,62). Se objetivó la tendencia a un mayor Q_A de la FAVI humeral en relación a la FAVI radial (1.323,6 ± 465,3 *versus* 1.017,4 ± 447,3 ml/min) (p = 0,052). Los pts con antecedente de AV previo, presentaron un Q_A medio significativamente superior (1.410,6 ± 377,7 ml/min) en relación a los restantes pts (1.034,4 ± 458,7 ml/min) (p = 0,013). No hemos objetivado ninguna correlación entre el Q_A medio y: edad, DEA, PAM, índice Kt/V, tiempo en HD y duración del AV. El Q_A medio obtenido mediante TDT fue similar al flujo sanguíneo medio determinado con el método Delta-H (1.151,3 ± 479,0 ml/min) (p = 0,89). Los valores del flujo sanguíneo del AV obtenidos mediante TDT se correlacionaron significativamente con los determinados con el método Delta-H (coeficiente de correlación intraclase = 0,95, p < 0,001).

***Conclusiones:* La TDT permite determinar QA durante la HD. El perfil funcional del AV fue peor en los pts con nefropatía diabética o sin antecedente de AV previo. Los valores de flujo sanguíneo del AV obtenidos mediante los métodos TDT y Delta-H se correlacionaron significativamente.**

Palabras clave: Acceso vascular. Flujo sanguíneo. Termodilución. Delta-H.

INTRODUCTION

In the most recent update of the K/DOQI Guidelines on vascular access (VA), regular measurement of blood flow (Q_A) in AV continues to be the preferred method for functional monitoring of VA.[1] Since 1995, several screening procedures based on indirect Q_A measurement have been introduced for non-invasive VA monitoring.[2-4] One of these is the thermodilution technique (TDT), a method that allows calculation of Q_A from the recirculation values obtained by the blood temperature sensor called BTM (Blood Temperature Monitor) with the hemodialysis (HD) lines in the normal and reverse positions.[5] This procedure, described and validated by Schneditz et al,[6] is easy to perform because the BTM sensor is integrated into the HD machine.

On the other hand, our department implemented in June 2000 a VA monitoring program consisting of regular measurement of Q_A during HD using the Delta-H method.[7] The purpose of this monitoring is early diagnosis of a 50% or greater stenosis of the vascular lumen and elective correction of stenosis by angioplasty or surgery before VA thrombosis occurs.[8] During the years of use, this monitoring program has been shown to be effective both for early diagnosis of significant VA stenosis (the Delta-H method has sensitivity and specificity higher than 80%) and for reduction of thrombosis prevalence.[3,7] In this regard, Wang et al showed that the recirculation values obtained with the BTM sensor provided a high sensitivity (81.8%) and specificity (98.6%) for detection of arteriovenous fistula (AVF) amenable to elective surgery.[9]

This was an observational, cross-sectional, comparative study using TDT aimed at measuring Q_A in VA during HD, analyze different variables that may have an impact on VA function, and perform a comparative functional study of the TDT and Delta-H methods.

MATERIAL AND METHODS

Patients

VA was monitored in 38 patients with renal failure on a chronic HD program. All patients underwent HD three times a week at the nephrology department of Hospital de Mollet through an indwelling VA cannulated by two puncutres. Patients with any previously documented sign of VA dysfunction were excluded. Variables analyzed included sex, age, primary nephropathy, time on HD, history of any comorbidity other than diabetes mellitus (ischemic heart disease, cerebrovascular disease, or peripheral artery disease), Kt/V index (by second-generation Daugirdas formulas, monocompartmental model), VA type, VA duration, history of prior VA, VA number/patient ratio. Table I summarizes the most significant characteristics of patients entering the study.

Method

1) *Q_A measurement by TDT.* Q_A was measured using the blood temperature sensor, BTM, incorporated into the Fresenius Medical Care model 4008-S machine. This dilution method, described and validated by Schneditz et al,[6] calculates Q_A from the recirculation values obtained with the HD lines in the normal and reverse positions. The measurement process starts from the production of a «temperature bolus» secondary to the self-limited decrease (2ºC for 2 minutes) in the temperature of the dialysis fluid. This thermal decrease is initially sensed by the temperature sensor of the venous line, and after traveling through the cardiopulmonary circulation of the patient, returns already reduced toward the dialyzer and is felt by the temperature sensor of the arterial line. Quantification of the last «arterial temperature bolus» in relation to the «venous temperature bolus» initially generated allows for calculating the recirculation percentage with the HD lines in a normal configuration. The same procedure is repeated with HD lines in a reverse configuration. Q_A is calculated from both recirculation values using the following formula:

$$Q_A = \frac{(Q_S - UFR) \cdot (1 - R_X - R_N + R_X \cdot R_N)}{R_X - R_X \cdot R_N - \left\{ \frac{Q_S - URF}{Q_S} \right\} \cdot (R_N - R_X \cdot R_N)}$$

where Q_S is the effective blood flow (mL/min), UFR the ultrafiltration rate (mL/min), R_N is recirculation obtained with the HD lines in normal position, and R_X is recirculation obtained with HD lines in reverse position. For adequate recirculation values to be obtained, both Q_S and UFR should be kept constant throughout measurement. Q_A was measured in duplicate during the first hour of 2 consecutive HD sessions, and the 2 values recorded were averaged. The distance between needles

Table I. Characteristics of patients and vascular accesses studied by TDT

Sex (%)	Male 71.1/Female 28.9
Mean age (years)	63.8 ± 15.1
Mean time on HD (months)	47.6 ± 53.9
Diabetic nephropathy (%)	18.4 (7/38)
Comorbidity (%)*	34.2 (13/38)
Kt/V Index	1.39 ± 0.21
Type of VA (%)	AVF** 94.7, PTFE prosthesis 5.3
Mean VA duration (months)	48.7 ± 69.8
Patients with prior VA (%)	36.8 (14/38)
Patients with prior VA on the same side (%)	78.6 (11/14)
VA number/patient ratio	1.63

* Proportion of patients having at least any of the following comorbidities: ischemic heart disease, cerebrovascular disease, peripheral artery disease.
** Radial and brachial AVFs each represent 50% (18 cases).

(DBN) and mean arterial pressure (MAP) (diastolic blood pressure + 1/3 of pulse pressure) were also recorded in both sessions.

2) *Q_A measurement by the Delta-H method.* Q_A was again measured within 15 days by the optodilutional Delta-H method, using the Crit-Line III monitor (ABF-mode, HemaMetrics, USA) in most patients (36/38, 94.7%). The Delta-H method could not be used in 2 cases because of kidney transplant and an acute coronary syndrome that required admission to the coronary unit respectively. This method, described and validated by Yarar et al,[10] is a photometric technique based on the reverse relationship existing between volemia and arterial hematocrit (Hct). Q_A was also measured during the first hour of HD dialysis from Hct changes related to sharp changes in UF (from 0.1 to 1.8 L/h) with HD lines in a normal or reverse configuration. Hct changes are continuously recorded by an optic sensor coupled to a blood chamber that is inserted between the dialyzer and arterial line. Q_A was calculated using the following formula:

$$Q_A = (\text{max UF} - \text{min UF}) \cdot \text{max rev Hct}/\text{rev Hct } \Delta - \text{nor Hct } \Delta$$

where max UF is maximum ultrafiltration, min UF is minimum ultrafiltration, max rev Hct is the maximum Hct obtained with HD lines in a reverse position, rev Hct Δ is the change in arterial Hct with reversed lines, and nor Hct Δ is the change in arterial Hct with HD lines in normal position.

All measurements by both procedures were performed by the same investigator.

Statistical study

Statistical data analysis was performed with SPSS software version 12.0 for Windows. Values are given as percentages or as mean ± standard deviation. The study comparing mean Q_A in VA between certain patients subgroups compared two by two was performed using a t test for two independent samples and a non-parametric Mann-Whitney's U test. A Pearson's correlation coefficient was calculated for the correlation analysis between mean Q_A in VA and the different quantitative variables studied. A diagnostic agreement analysis was done by calculating the intraclass correlation coefficient between blood flow values in the VA measured by the Delta-H and TDT methods (fixed factor) on the same patient sample (random factor). A value of $p < 0.05$ was considered statistically significant.

RESULTS

Mean Q_A measured by TDT was 1,170.5 ± 464.2 mL/min (range, 289.4-2,346.4 mL/min). Most VAs (44.7%) had a mean Q_A ranging from 1,000 and 1,500 mL/min (table II). Mean DBN and MAP were 6.2 ± 2.9 cm and 91.9 ± 12.4 mmHg respectively.

Table III shows 10 different variables based on the mean Q_A recorded. Q_A was similar for both patients with MAP values both lower or higher than 100 mmHg (p = NS). Patients with diabetic nephropathy had a significantly lower Q_A (836.1 ± 395.8 mL/min) as compared to all other patients (1,245.9 ± 449.9 mL/min) (p = 0.033). No differences were found in mean Q_A when patients with any comorbidity other than diabetes and with no comorbidities were compared (p = NS). A trend was noted to a higher Q_A in the brachial AVF as compared to the radial AVF (1,323.6 ± 465.3 *versus* 1,017.4 ± 447.3 mL/min) (p = 0.052). Patients with a history of prior VA had a significantly higher mean Q_A (1,410.6 ± 377.7 mL/min) as compared to all other patients (1,030.4 ± 458.7 mL/min) (p = 0.013).

No correlation was found between mean Q_A and the following variables: age (r = -0.25, p = 0.13), DBN (r = -0.08, p = 0.61), MAP (r = -0.021, p = 0.90), Kt/V index (r = 0.078, p = 0.64), time on HD (r = 0.29, p = 0.07), and VA duration (r = -0.023, p = 0.89).

Mean Q_A measured by TDT was similar to the mean blood flow measured using the Delta-H method (1,151.3 ± 479.0 mL/min) in 36 patients (p = 0.89). Blood flow values in the VA recorded by TDT significantly correlated to those measured using the Delta-H method (intraclass correlation coefficient = 0.95, $p < 0.001$). The Bland-Altman plot in figure 1 shows the agreement between both procedures.

DISCUSSION

Q_A values measured by TDT are very similar to those reported in other series by different authors using different non-invasive methods to calculate Q_A. Table IV shows some of these methods, selected based on the greater prevalence of AVF, which is the type of VA most prevalent in our setting.[16]

In this study, a significant difference was found in VA function between patients with diabetic nephropathy and all other

Table II. Distribution of VA depending on the different Q_A segments considered

mean Q_A (mL/min)	VA (%)
< 700	15.8 (n = 6)
700-1.000	21.1 (n = 8)
1,001-1,500	44.7 (n = 17)
> 1,500	18.4 (n = 7)

Table III. Mean Q_A recorded depending on the different variables considered

Variable	N	Mean Q_A by TDT (mL/min)	p
Age < 65 years	19	1,268.8 ± 484.7	0.19
Age ≥ 65 years	19	1,072.2 ± 433.2	
Male	27	1,099.5 ± 414.7	0.14
Female	11	1,344.8 ± 550.6	
Diabetic nephropathy	7	836.1 ± 395.8	0.033
All other causes of ESRD	31	1,245.9 ± 449.9	
At least 1 comorbidity	13	1,116.9 ± 483.0	0.62
No comorbidities	25	1,198.3 ± 461.7	
Radial AVF	18	1,017.4 ± 447.3	0.052
Brachial AVF	18	1,323.6 ± 465.3	
VA duration < 24 months	20	1,093.7 ± 522.8	0.29
VA duration ≥ 24 months	18	1,255.8 ± 385.9	
No prior VA	24	1,030.4 ± 458.7	0.013
Prior VA	14	1,410.6 ± 377.7	
Distance between needles < 6 cm	19	1,226.9 ± 470.3	0.46
Distance between needles ≥ 6 cm	19	1,114.0 ± 463.8	
MAP < 100 mmHg	26	1,180.6 ± 402.8	0.85
MAP ≥ 100 mmHg	12	1,148.5 ± 596.1	
Kt/V index < 1.30	13	1,094.5 ± 562.3	0.47
Kt/V index ≥ 1.30	25	1,210.0 ± 411.5	

patients. Diabetic patients had a lower Q_A (< 1,000 ml/min) as compared to all other patients, though sufficient to ensure adequate dialysis. This functional difference may be explained by the greater prevalence of vascular calcifications in diabetic patients.[17,18] In this regard, in the multivariate study conducted by Tonelli et al, in which 4,084 Q_A measurements were performed in 294 patients with AVF using the ultrasound dilution method, diabetes mellitus was, together with overweight and systolic blood pressure, a variable independently associated to Q_A, so that AVF function was always significantly lower in diabetic patients (788 ± 580 *versus* 1,054 ± 681 mL/min)[19]. This functional impairment may result in a decreased VA survival in diabetic patients.[16,20,21] In Spain, according to data from the Registre de Malalts Renals de Catalunya, in addition to patient age and time on dialysis, diabetes mellitus is one of the factors having a negative impact on VA duration.[16]

In most cases, maturation of a more proximal secondary AVF is promoted by venous changes resulting from a previously functioning ipsilateral VA.[22,23] In this study, VA function was better in patients with history of a prior VA. Existence of a prior venous arterialization in most of these patients

Table IV. Mean Q_A measured in other series by different authors using different non-invasive monitoring methods

Author	VA number	% AVFs	Method	Q_A (mL/min)
Lindsay et al.[11]	41	61	Differential conductivity	1,140 ± 680
Begin et al.[12]	45	100	Ultrasound dilution	1,132 ± 681
Roca-Tey et al.[13]	32	100	TQA	1,038 ± 513
Yarar et al.[10]	65	60	Delta-H	1,050 ± 460
Roca-Tey et al.[7]	145	84	Delta-H	1,167 ± 473
Wijnen et al.[14]	40	65	TDT	1,034 ± 527
Giorgi et al.[15]	29	86	TDT	942 ± 361
Roca-Tey et al.*	38	95	TDT	1,170 ± 464

*Current study.

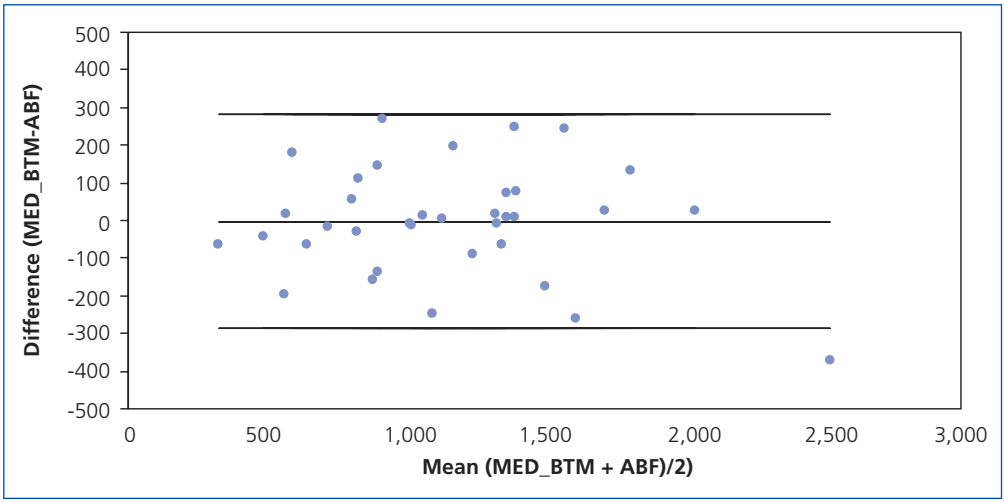

Figure 1. Bland-Altman plot showing agreement between the Delta-H y TDT screening methods for measuring Q_A.

(78.6%) may account for this functional difference. That is, history of a functional VA located more distal in the same limb may condition function of a new proximal secondary AVF. In this regard, in the Begin et al series including 45 patients with AVFs, Q_A values of patients with brachiocephalic AVF, as measured by the ultrasound dilution method, were higher in patients with history of a previously functioning radiocephalic AVF in the same arm than in those with no such history (1,800 ± 919 *versus* 1,167 ± 528 mL/min)[12]

Our study demonstrated the functional agreement between the TDT and Delta-H methods. No significant differences were found between the VA blood flow values recorded by both procedures. Other authors reported similar results after comparing blood flow values in VA measured by TDT and the ultrasonic dilution method.[6,14] In fact, in the initial series of Schneditz et al, comprising 18 VAs (only 33.3% AVFs), the Q_A value recorded by TDT was 1,328 ± 627 mL/min, very similar to the value found by ultrasonic dilution, 1,390 ± 657 mL/min.[6] In the more recent Wijnen et al series, involving 40 Vas /65% AVFs), no difference was found in the Q_A values measured by the ultrasonic dilution and TDT methods (1,053 ± 495 y 1,034 ± 527 mL/min, respectively).[14]

The functional comparison between the Delta-H and TDT methods could be considered as a limitation of this study, because most comparative functional studies conducted used the ultrasound dilution method as the reference procedure. However, the efficacy of the Delta-H method for VA monitoring has already been adequately documented.[3,7] Moreover, according to the recent European Guidelines on vascular access, no clear preference exists for any of the reported procedures for measuring Q_A.[24]

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