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Noninvasive assessment of forearm vessels by color Doppler ultrasonography (CDU) before and after creation of radiocephalic fistula (RCF)

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SUMMARY

Introduction: *The CDU is a noninvasive vascular access (VA) monitoring technique that provides both structural and hemodynamic information from vessels.*

Objective: *The aim of this prospective study was to analyze some parameters of forearm vessels by CDU before and after RCF creation at the wrist.*

Patients and methods: *We explored by CDU the vessels 15.1 yr, sex M:76.5%; F:23.5%, ± of forearm in 34 CRF patients (pts) (mean age 63.9 26.5% diabetes, 73.5% already on HD at the time of RCF placement). Forearm CDU evaluation was planned twice: before RCF creation (first exploration FE) and after two months of successful RCF cannulation for HD by 2 needles at Qb > 250 ml/min (second exploration SE). All CDU examinations were performed by the same 60°) at two£radiologist with 5-10 MHz linear transducer (Doppler angle proximal and distal points of the forearm (the values were averaged) using the Aspen machine (Siemens-Acuson, Mountain View, CA). We measured by CDU parameters from radial artery RA (diameter RAd, peak systolic velocity PSV, resistive index RI, blood flow rate RAflow), cephalic vein CV (diameter CVd) and arterialized vein AV (diameter AVd, blood flow rate AVflow). RAflow or AVflow calculation by CDU: time average velocity (mean of three cardiac cycles) (m/s) x cross-sectional area (mm^2) x 60. RCF outcome: functioning RCF (FRCF) suitable 14.5 yr, 23.8% diabetes), or non-functioning ± for routine HD 61.8% (mean age 61.2 15.5 yr, 30.8% diabetes) due to: early thrombosis ± RCF 38.2% (mean age 68.2 (within 24 hours after operation, ETRCF) 14.7%, lack of RCF maturation (LMRCF) 5.9%, last thrombosis (between 24 hours after operation and SE by CDU, LTRCF) 0.3* vs *± 17.6%.*

Results: *Between FE and SE by CDU at RA, overall mean RAd (3.2 27.4 ± 58.2 cm/s) and mean RAflow (67.9 ± 12.4* vs *166.6 ± 1.0 mm), mean PSV (59.9 ± 5.5 683.1 ml/min) increased significantly (for all comparisons, ±* vs *1297.1 p < 0.1) decreased significantly ± 0.2* vs *0.4 ± 0.001), and mean RI (0.9 (p < 0.001); we also found a significant difference when overall mean CVd 1.1 mm) were compared (p ± 0.6 mm) and mean AVd (5.7 ± (2.9 < 0.001). Overall and 19.6 and±distal mean RAflow at FE by CDU were lower in pts with ETRCF (33.6 27.4 and ± 16.7 ml/min, respectively) compared to pts with FRCF (67.9 ± 26.0 21.3 ml/min, respectively) (p = 0.015 and p = 0.029, respectively). Pts with ± 48.0 0.4 ± ETRCF and LMRCF considered together (20.6%), had lower overall mean RAd (2.8 15.2 ml/min) at FE by CDU compared to pts with ± mm) and distal mean RAflow (28.1 21.3 ml/min, respectively) (p = 0.015 and p = 0.031, ± 0.3 mm and 48.0 ± FRCF (3.2 respectively). No significant differences between pts with*

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LTRCF and FRCF were found when overall and distal mean RAd, PSV, RI, RAflow and CVd obtained at FE by CDU were compared (for all comparisons, p = NS), but all pts with LTRCF underwent HD at the time of RCF creation compared to 57.1% of pts with FRCF (p = 0.049). Pts with FRCF who had overall mean AV-flow ≤ 800 ml/min (38.1%, mean 167.3 ml/min) showed lower overall mean RA-flow at SE by CDU ± AVflow: 602.5 compared to pts with FRCF who had overall mean AVflow > 800 ml/min (61.9%, mean 715.4 ml/min (p = 0.002). We ± 188.7 vs *1590.7 ± 160.1 ml/min): 820.1 ± AVflow: 1113.9 found a positive correlation between overall mean AVflow and mean RAflow obtained at SE by CDU (r = 0.52, p = 0.016).*

Conclusions: *1) All parameters of forearm vessels measured by CDU changed after RCF placement. 2) Preoperative mean RAflow is predictive of RCF outcome. 3) Mean AVflow is related to mean RAflow obtained at SE by CDU.*

Key words: ***Color Doppler Ultrasonography. Radiocephalic fistula. Radial artery flow. Arterial flow.***

EXPLORACIÓN VASCULAR NO INVASIVA DEL ANTEBRAZO MEDIANTE ECOGRAFÍA DOPPLER COLOR (EDC) ANTES Y DESPUÉS DE LA CONSTRUCCIÓN DE LA FÍSTULA RADIOCEFÁLICA (FRC)

RESUMEN

Introducción: *La EDC permite efectuar un estudio anatómico y funcional del árbol vascular.*

Objetivos: *Analizar diferentes parámetros de los vasos sanguíneos del antebrazo por EDC antes y después de la construcción de la FRC en el carpo.*

Material y métodos: *Hemos explorado prospectivamente el antebrazo de 34 pacientes (pts) con IRC (edad 63,9 años, sexo H: 76,5%; M: 23,5%, 26,5% diabetes, 73,5% ya efectuaban HD en el momento de efectuar la FRC) mediante EDC. La evaluación por EDC se planificó por duplicado: antes de la creación de la FRC (primera exploración PE) y dos meses después de la punción sin problemas de la FRC con 2 agujas y Qb > 250 ml/min (segunda exploración SE). Todas las exploraciones se efectuaron por el mismo radiólogo mediante un transductor lineal de 5-10 MHz (monitor de EDC Aspen, Siemens-Acuson, Mountain View, CA) aplicado sobre 2 puntos diferentes (proximal y distal) del antebrazo (ambos valores se promediaron). Se determinaron por EDC parámetros de la arteria radial AR (diámetro d AR, velocidad máxima sistólica VMS, índice de resistencia IR, flujo sanguíneo flujo AR), vena cefálica VC (diámetro d VC) y vena arterializada VA (diámetro dVA, flujo sanguíneo flujoVA). Cálculo de flujoAR o flujoVA por EDC (ml/min): curva tiempo-velocidad (media de 3 ciclos cardíacos) (m/s) x área transversal (mm^2) x 60. Seguimiento de la FRC: FRC funcionante (FRCF) 61,8%, o FRC no funcionante 38,2% por: trombosis inicial (durante las 24 horas siguientes a la intervención, TIFRC) 14,7%, falta de maduración (FMFRC) 5,9%, trombosis tardía (entre las 24 horas post-intervención y la SE por EDC, TTFRC) 17,6%.*

Resultados: *Entre PE y SE por EDC sobre la AR, 12,4 vs ± 1,0 mm), VMS (59,9 ± 0,3* vs *5,5 ± los valores globales de dAR (3,2 683,1 ml/min) aumentaron (para ± 27,4* vs *1297,1 ± 58,2 cm/s) y flujoAR (67,9 ± 166,6 todas las comparaciones, p < 0,1) disminuyó ± 0,2* vs *0,4 ± 0,001), y el IR (0,9 (p < 0,6 mm) y ± 0,001); también diferencia significativa al comparar dVC (2,9 1,1 mm) globales (p ± dVA (5,7 < 0,001). El flujoAR medio global y distal 16,7 ± 19,6 y 26,0 ± obtenido en la PE por EDC fue menor en los pts con TIFRC (33,6 21,3 ± 27,4 y 48,0 ± ml/min, respectivamente) en relación a los pts con FRCF (67,9 ml/min,*

respectivamente) (p = 0,015 y p = 0,029, respectivamente). En la PE por EDC, los pts con TIFRC y FMFRC considerados conjuntamente (20,6%), presentaron menor 15,2 ml/min) en ± 0,4 mm) y flujoAR medio distal (28,1 ± dAR medio global (2,8 21,3 ml/min, respectivamente) ± 0,3 mm y 48,0 ± relación a los pts con FRCF (3,2 (p = 0,015 y p = 0,031, respectivamente). Sin diferencias entre los pts con TTFRC y FRCF al comparar dAR, VMS, IR, flujoAR y dVC medio global y distal obtenidos en la PE por EDC (para todas las comparaciones, p = NS), pero todos los pts con TTFRC ya estaban en programa de HD cuando se construyó la FRC en relación a 57,1% de los pts con FRCF (p = 0,049). Los pts con FRCF y flujoVA global medio ≤ 800 ml/min 167,3 ml/min) presentaron un flujoAR global medio menor ± (38,1%, flujoVA: 602,5 en la SE por EDC en relación a los pts con FRCF y flujoVA global medio > 800 715,4 ml/min ± 188,7 vs *1590,7 ± 160,1 ml/min): 820,1 ± ml/min (61,9%, flujoVA: 1113,9 (p = 0,002). Hemos objetivado una correlación positiva entre flujoVA y flujoAR medio global obtenidos en la SE por EDC (r = 0,52, p = 0,016).*

Conclusiones: *1) Todos los parámetros vasculares del antebrazo determinados por EDC cambian tras la construcción de la FRC. 2) El flujoAR obtenido antes de la intervención es predictivo de funcionamiento de la FRC. 3) El flujoVA está en relación con el flujoAR obtenido en la SE por EDC.*

Palabras clave: ***Ecografía Doppler color. Fístula radiocefálica. Flujo de la arteria radial. Flujo de la vena arterializada.***

INTRODUCTION

Color Doppler ultrasonography (CDU) is an imaging technique allowing for noninvasive examination of the vascular tree comprising the following features:[1-5]

1) *Pre-surgical vascular planning*. Several studies have showed that doing a vascular map by CDU before creating a vascular access significantly increases the prevalence of patients dialyzed through an internal arteriovenous fistula (IAVF). This is due to a decrease in the number of cases with initial thrombosis and lack of IAVF maturation, as well as decreased placement of PTFE synthetic grafts.[1,2]

2) *Morphologic monitoring of the vascular access VA*. CDU allows visualizing and quantifying AV stenosis.[3,4]

3) *Hemodynamic information of the VA*. CDU allows for direct determination of VA blood flow and thus its functional follow-up.[4]

4) *Imaging support for VA elective management*. In some cases, CDU has been successfully used as an imaging tools during angioplasty of VA stenosis.[5]

In the present work, we have performed an observational, prospective and comparative study analyzing the different variables of the forearm vessels by using CDU before and after the creation of a radiocephalic fistula (RCF) at the carpus level, with the following objectives:

1) To assess the changes in several morphologic and functional parameters of the forearm blood vessels after the creation of a RCF.

2) To identify the predictive variables of RCF functioning before performing arteriovenous anastomosis.

3) TO study the factors having an effect on RCF function during chronic dialysis.

MATERIAL AND METHODS

Patients

Between December of 2003 and November of 2005, we have prospectively examined by CDU the forearm vessels of 34 patients suffering from chronic renal failure (CRF). Mean age was 63.9 ± 15.1 years (range, 35-85 years). There was a preponderance of the male gender (76.5%). The prevalence of diabetic nephropathy was 26.5% of the cases. Most of the patients were already on hemodialysis through central catheter at the time of RCF creation (73.5%). Forearm examination by CDU was planned twice: before the creation of the RCF [first examination (FE)] and two months after incident-free puncture of the RCF with 2 needles and Q_b > 250 mL/min [second examination (SE)].

Methods

The same radiologist did all CDU examinations with a 5-10 MHz linear probe (Aspen CDU monitor, Siemens-Acuson, Mountain View, CA) applied on two different proximal and distal sites of the forearm (both values were averaged). The examination angel was £60º. The following vascular parameters were determined by CDU:

1) Radial artery: diameter, maximal systolic velocity, resistance index, and blood flow.
2) Cephalic vein: diameter.
3) Arterialized vein: diameter and blood flow.

The calculation of the radial artery or arterialized vein blood flow by CDU (mL/min) was done with the following formula: time-velocity curve (mean of 3 cardiac cycles) (m/s) ¥ cross-sectional area (mm^2) ¥ 60.

About follow-up of the RCF from its creation, *i.e.* the functional state of the RCF at the time of the SE by CDU, we have observed two types of situations:

1) Functional RCF (FRCF): 61.8% (21/34) or
2) RCF not useful for chronic dialysis (38.2%) due to:

– Initial thrombosis (ITRCF): within the 24 hours following surgery (14.7%, 5/34).
– Lack of maturation (LOMRCF): 5.9% (2/34).
– Late thrombosis (LTRCF): between 24 hours after the surgery and the SE by CDU: 17.6% (6/34).
– Mean time between FE by CDU and the creation of RCF was 52.0 ± 61.5 days (range, 1-200 days).

Statistical analysis

The data statistical analysis was done by using the SPSS software, version 12.0 for Windows. The values are expressed as percentages or mean ± standard deviation. The differences between related means obtained from the different variables when comparing FE and SE by CDU were analyzed by t-test for paired data and the Wilcoxon's nonparametric test. The two-by-two comparative study of the different continuous variables between particular subgroups of patients was done by the t test for two independent samples and the Mann-Whitney U test. The correlation analysis between mean whole blood flow of the arterialized vein and the different quantitative variables studied at SE by CDU was calculated by the Pearson's correlation coefficient. A p value < 0.05 has been considered statistically significant.

RESULTS

Between the FE and SE by CDU of the radial artery, proximal, distal, and total values (the average of proximal and distal values) of diameter, maximal systolic velocity and blood flow significantly increased and the resistance index significantly decreased (for all comparisons, $p < 0.001$). We also observed a significant difference when comparing the diameter of the cephalic vein and that of the arterialized vein, at both proximal and distal levels, and total (for all comparisons, $p < 0.001$) (Table I).

About the parameters regarding the forearm blood vessels studied at FE by CDU, we have undertaken a comparative study between patients with FRCF and the following subpopulations:

1) Patients with ITRCF. Mean total and distal blood flow of the radial artery obtained at FE by CDU was lower in patients with ITRCF (33.6 ± 19.6 and 26.0 ± 16.7 mL/min, respectively) as compared to patients with FRCF (67.9 ± 27.4 and 48.0 ± 21.3 mL/min, respectively) ($p = 0.015$ and $p = 0.029$, respectively).
2) Patients with ITRCF and LOMRCF considered as a whole (20.6%, 7/34). These patients had lower mean total diameter (2.8 ± 0.4 mm) and distal mean blood flow (28.1 ± 15.2 mL/min) of the radial artery as compared to patients with FRCF (3.2 ± 0.3 mm and 48.0 ± 21.3 mL/min, respectively) ($p = 0.015$ and $p = 0.031$, respectively).

Tabla I. Changes in global values (average of proximal and distal values) for several forearm vascular parameters obtained by CDU, as compared with creation of the RCF. The same level of statistical significance has been obtained when examining separately all these parameters at the proximal and distal forearm level by CDU

Variable	FE by CDU	SE by CDU	p
RAd (mm)	3.2 ± 0.3	5.5 ± 1.0	< 0,001
MSV (cm/s)	59.9 ± 12.4	166.6 ± 58.2	< 0,001
Raflow (mL/min)	67.9 ± 27.4	1297.1 ± 683.1	< 0,001
RI	0.99 ± 0.19	0.41 ± 0.06	< 0,001
CVd_AVd (mm)	2.9 ± 0.6	5.7 ± 1.1	< 0,001

FE, first examination; SE, second examination; CDU, color Doppler ultrasonography; RAd, radial artery diameter; MSV, maximal systolic velocity; RAflow, blood flow of the radial artery; RI, resistance index; CVd, cephalic vein diameter; AVd, arterialized vein diameter.

3) Patients with LTRCF. We have not observed differences between patients with LTRCF and FRCF when comparing the diameter of the radial artery, maximal systolic velocity, resistance index, blood flow of the radial artery and diameter of the cephalic vein, at both distal level and total, obtained at FE by CDU (for all comparisons, p = NS). However, all LTRCF patients were already on HD program through catheter (as their first VA (66.6%) or due to previous IAVF thrombosis (33.4%)) when the RCF was created, as compared to 57.1% of the patients with FRCF (p = 0.049).

In none of these comparisons we have found differences by age, gender, or diabetes prevalence (for all cases, p = NS).

We have classified the patients with FRCF in two subgroups according to mean global blood flow of the arterialized vein (919.1 ± 299.9 mL/min) obtained at SE by CDU:

1) Patients with global blood flow of the arterialized vein ≤ 800 mL/min (602.5 ± 167.3 mL/min): 38.1% (8/21).
2) Patients with global blood flow of the arterialized vein > 800 mL/min (1113.9 ± 160.1 mL/min): 61.9% (13/21).

We have compared both subpopulations and we have not found differences by age, gender, diabetes prevalence, or most of the parameters studied at SE by CDU of the radial artery (diameter, resistance index and maximal systolic velocity) and of the arterialized vein (diameter) (for all comparisons, p = NS). However, those patients with lower blood flow of the arterialized vein (≤ 800 mL/min) had mean global blood flow of the radial artery significantly lower (820.1 ± 188.7 mL/min) as compared to the remaining patients (1590.7 ± 715.4 mL/min) at SE by CDU (p = 0.002) (Table II).

We have carried out a correlation analysis between mean global blood flow of the arterialized vein and several variables studied at SE by CDU. We have only found a significant correlation between global blood flow values of the arterialized vein and those of the radial artery (r = 0.52, p = 0.016) (Table III).

Table II. Comparative study between 2 subpopulations of patients with FRCF by mean global blood flow of the arterialized vein obtained at SE by CDU

Variable	AVflow ≤ 800 mL/min	AVflow > 800 mL/min	p
N	8/21 (38.1%)	13/21 (61.9%)	
Age (years)	64.0 ± 15.3	59.5 ± 14.3	0.45
Gender (%)	Male 75 / Female 25	Male 69.2 / Female 30.8	0.77
Diabetes prevalencia (%)	25	23.1	0.92
AVd (mm)*	5.4 ± 0.8	5.9 ± 1.2	0.31
RAd (mm)*	5.1 ± 0.4	5.8 ± 1.2	0.16
RI*	0.42 ± 0.05	0.39 ± 0.07	0.38
MSV (cm/s)*	152.6 ± 54.0	175.2 ± 61.1	0.25
RAflow (mL/min)*	**820.1 ± 188.7**	**1590.7 ± 715.4**	**0.002**

*Several vascular variables of the forearm studied at SE by CDU; all are global values and have been obtained from averaged proximal and distal forearm determinations. AVflow, blood flow of the arterialized vein; AVd, arterialized vein diameter; RAd, radial artery diameter; RI, resistance index; MSV, maximal systolic velocity; RAflow, blood flow of the radial artery.

DISCUSSION

In our study, all values obtained when examining the vascular parameters of the forearm at the first ultrasonographic check-up, i.e., before performing the arteriovenous anastomosis, were significantly modified when at the SE by CDU. In the series by Mahmutyazicioglu *et al.*, in which they reported 28 CRF patients studied by CDU before and after the creation of a RCF all the determinations obtained when exploring several parameters of the radial artery before the surgery were significantly changed from the after creation of the FRC;[6] in this study, the blood flow of the radial artery was increased from 31.6 ± 15.9 mL/min before de intervention to 739.3 ± 193.8 mL/min the day following the surgery.[6] The ultrasonographic study by Marko Malovrh reported 35 patients submitted to RCF in whom the blood flow of the radial artery before the intervention (< 50 mL/min) progressively increased after the creation of

Table III. Correlations between mean global blood blow of the arterialized vein and several vascular variables of the forearm studied at SE by CDU. All values have been obtained from averaged proximal and distal determinations of the forearm

Global forearm variables	Global AVflow (mL/min)
RAd (mm)	r = 0.25 / p = 0.27
RI	r = – 0.07 / p = 0.75
MSV (cm/s)	r = 0.22 / p = 0.34
RAflow (mL/min)	**r = 0.52 / p = 0.016**
AVd (mm)	r = 0.27 / p = 0.24

AVflow, blood flow of the arterialized vein; RAd, radial artery diameter; RI, resistance index; MSV, maximal systolic velocity; RAflow, blood flow of the radial artery; AVd, arterialized vein diameter.

the RCF, already within the 24 hours following the intervention and continued during the next weeks until the end of the study period (blood flow of the radial artery > 400 mL/min at week 12).[7]

The blood flow of the radial artery obtained in our work before the intervention is predictive of the RCF functioning. Patients with ITRCF and/or LOMRCF presented significantly lower blood flow of the radial artery (< 40 mL/min) at FE by CDU, as compared to the remaining patients. That is to say, the function of the radial artery existent before the surgery is decisive to assure the permeability and maturation of the RCF. In another series, Marko Malovrh reported 116 CRF patients studied by means of CDU before and after the creation of a RCF, patients in whom the RCF get thrombosed immediately after or within 24 hours of anastomosis creation presented a pre-surgery flow of the radial artery significantly lower (24.1 ± 16.8 mL/min) as compared with those patients with permeable RCF (54.5 ± 22.8 mL/min).[8] In the work by Korsoy *et al.*, the blood flow of the humeral artery was studied by CDU before the creation of a PTFE humeral-axilar in 17 patients: the prostheses getting thrombosed within one year of follow-up presented pre-surgery flow of the humeral artery significantly lower (66 mL/min) as compared with permeable prosthesis (87 mL/min) and, moreover, no prosthesis got thrombosed during the follow-up when the pre-surgical blood flow was > 70 mL/min.[9] In the series by Yerdel *et al.*, referred to 32 CRF patients submitted to IAVF, only 21% of the patients with a pre-surgical flow of the nurturing artery < 40 mL/min determined by CDU presented a blood flow of the arterialized vein > 600 mL/min, and conversely most of the patients (66.6%) with pre-surgical flow of the nurturing artery ≥ 40 mL/min presented a blood flow of the arterialized vein > 600 mL/min.[10]

In the present study, we have not found any difference between patients with LTRCF and FRCF when comparing the vascular parameters at FE by CDU. However, all patients with LTRCF were already on hemodialysis when the RCF was created, as compared with 57.1% of the patients with FRCF. It may be possible that in some patients with LTRCF hemodialysis-related hemodynamic changes (arterial hypotension) may contribute to thrombosis of the RCF. In this sense, in the series by Zeebregts *et al.*, referred to 153 CRF consecutive patients in whom a RCF was created, starting on hemodialysis before the creation of RCF was an independent predictive factor for RCF thrombosis within the 3 months following surgery.[11] Similarly, the study by Feldman *et al.*, referred to 348 patients submitted to IAVF, dialysis onset before the creation of the vascular anastomosis was an independent variable decreasing by 50% the likelihood of appropriate maturation of the IAVF.[12] The fact that most of the patients with LTRCF (66.6%) were already on dialysis through a central catheter as their first VA at the time of creation of the RCF highlights the importance of early creation of an IAVF and assuring its correct development before starting the hemodialysis program.

In our work, once the RCF is normally used for chronic hemodialysis, the main determinant of the flow of the arterialized vein is the blood flow coming from the radial artery. Already in previous studies performed in our Department,[4] we have observed that the blood flow of the arterialized vein has been correlated with the parameters obtained by examining the nurturing artery (arterial diameter and blood flow) by CDU. The existence of arterial pathology, which is more and more frequent because of the increasing age and higher diabetes and peripheral arteriopathy prevalence in CRF patients, may affect the flow of the nurturing artery and, thus, compromise the function of the arterialized vein.[13-15]

In summary, the blood flow of the radial artery determined by CDU is paramount both for achieving RCF permeability and normal maturation after the creation of the arteriovenous anastomosis sea and for further maintenance of its appropriate functioning during chronic dialysis.

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