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Digital pressure in haemodialysis patients with brachial arteriovenous fistula

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***Background & objectives*: The pathophysiological mechanisms involved in distal pressure changes following arteriovenous fistula (AVF) creation in patients with end-stage renal disease (ESRD) are not completely understood. This study was aimed to assess digital pressure changes post-AVF creation and to identify the factors that might influence these changes in ESRD patients.**

***Methods*: In this prospective study, 41 patients with ESRD underwent AVF creation. Basal digital pressure (BDP), digital brachial index (DBI), calcium, phosphorus and blood urea levels were assessed preoperatively. BDP, DBI, vein and artery diameters, and AVF blood flow were also evaluated at one and two month(s) post-AVF creation.**

***Results*: Mean BDP significantly decreased from 131.64±25.86 mmHg (baseline) to 93.15±32.14 and 94.53±32.90 mmHg at one and two months post-AVF creation, respectively (*P*<0.001). Mean DBI significantly decreased one month post-AVF creation versus baseline (0.70±0.18 vs. 0.89±0.17 mm, *P*<0.001) and remained similar at two versus one month(s) postoperatively (0.70±0.23 vs. 0.70±0.18 mm). At both postoperative timepoints, no correlation between DBI decrease and increased artery and vein diameters or fistula blood flow was observed. Mean DBI difference between patients with previous ipsilateral access versus those without was not significant from pre to one month postoperatively. No correlation was observed between baseline phosphorus, calcium and blood urea nitrogen and DBI changes.**

***Interpretation & conclusions*: Our findings suggest that decrease in distal pressure following AVF creation may not be influenced by the arterial remodelling degree, vein diameter or fistula flow. In uraemic patients, those with low calcium and/or increased phosphorus, no association between these parameters and DBI changes could be observed.**

Key words Arteriovenous fistula - digital pressure - haemodialysis - mineral metabolism

In patients with end-stage renal disease (ESRD) who undergo surgical arteriovenous fistula (AVF) creation to provide the vascular access necessary for renal haemodialysis, changes in digital pressure can occur following AVF creation. It has been shown that the decreased digital pressure is not consistently associated with the clinical evidence of ischaemia[1], although in some cases, it may cause pain at rest and necrosis, leading to haemodialysis access-induced distal ischaemia (HAIDI) (also known as access-related hand ischaemia, distal hypoperfusion ischaemic syndrome or arterial steal syndrome). A better understanding of the pathophysiological mechanisms involved in HAIDI occurrence is crucial for early detection of the 'at risk' patients and it would permit adopting an early therapeutic strategy[2-4].

It has been suggested that the poor remodelling of the arterial tree of the arm combined with pressure loss at the arteriovenous anastomosis, which occurs in some patients following AVF creation, could be a cause of HAIDI occurrence[5]. However, another group has shown that the decreased digital pressure occurs immediately after the surgery, without worsening in the first month, during which period, the arterial remodelling takes place[6]. Different studies suggest that the high AVF flow may cause gradual loss of blood from the forearm arteries of the same arm and lead to decreased digital pressure, followed by peripheral ischaemia[5,7,8]. In addition, in many forearm and proximal arteriovenous access, the clinically silent reversal of lower arm arterial blood flow (defined as arterial steal) can also be observed[7,8]. However, its presence does not predict or is not necessarily correlated with HAIDI[1], and it has been shown that HAIDI occurrence is more likely related to locoreginal hypotension caused by the loss of blood pressure at AVF location, because of a disturbed blood flow pattern in the anastomotic area[5]. Occlusive arterial stenosis occurring within the arteries of the upper extremity (*i.e.* proximal arteries), as well as the distal arteriopathy caused by vascular calcification, may also be involved in HAIDI pathogenesis[9,10]. The high flow accesses have been identified as having a greater risk for HAIDI than normal flow AVFs, although a normal flow combined with atherosclerosis may lead to the same outcome[11]. van Hoek *et al*[12], using a questionnaire to achieve a better selection of patients with clinical symptoms, have observed that patients with low AVF flow may also exhibit HAIDI. Therefore, high flow is not conditional for HAIDI[7].

Changes in calcium and phosphorus metabolism in patients with ESRD are frequently encountered. Greater calcification of the coronary artery, aortic and peripheral artery atherosclerotic plaques were also observed in these patients, leading to increased cardiovascular mortality and AVF failure rate[13]. Although the hardening of the arterial walls and stenosis may be involved in the occurrence of HAIDI, the role played by the mineral metabolism changes in digital pressure variation is not known.

In our study, it was hypothesized that in ESRD patients with brachial fistula accesses, the digital pressure changes following AVF creation might be associated with the AVF flow, enlargement of the vein and artery diameters after AVF creation. Considering that ESRD patients commonly have changes in the calcium, phosphorus and blood urea nitrogen (BUN) metabolism, it was also assumed that the preoperative levels of calcium, phosphorus and BUN could be correlated with digital brachial index (DBI) changes overtime.

To test this hypothesis, digital pressure changes were assessed following AVF creation at brachial level in patients with ESRD. The association between levels of calcium, phosphorus and BUN and digital pressure changes, if any, was also evaluated.

Material & Methods

This prospective study was planned to enrol all patients with ESRD who underwent brachial AVF creation between January 8, and August 1, 2014. The study was conducted in the department of Cardiovascular Surgery of the academic hospital 'Niculae Stancioiu' Heart Institute in Cluj-Napoca, Romania. The patients included were diagnosed with ESRD in dialysis centres from seven cities in Romania, and they were referred to 'Niculae Stancioiu' Heart Institute for AVF creation. The brachial arteriovenous anastomosis was performed by a single vascular surgeon, and each patient was followed up for a period of two months after AVF creation.

The study protocol was approved by the research ethics committee of 'Iuliu Hatieganu' University of Medicine and Pharmacy, Cluj-Napoca, Romania. All patients provided the informed written consent for inclusion in the study.

The study inclusion criteria were patients diagnosed with ESRD suitable for AVF creation at brachial artery (participants with cephalic and basilic vein diameters arm >1.7 mm and brachial artery diameter >2 mm were considered eligible; criteria were established based on previously published data[14], with a slight modification); and functional AVF at four weeks after creation. Patients with brachial AVF only were included in the study, because it has been shown that the prevalence of HAIDI is more common in patients with proximal accesses than in the ones with distal accesses[11,15]. The study exclusion criteria were patients suitable for radial AVF creation (radial artery diameter >1.5 mm and cephalic vein diameter at the forearm >1.7 mm, as suggested by previously published data[14,16]); stenosis or thrombosis of the veins planned to be used for AVF creation; concomitant diagnosis of clinical/subclinical bacterial infection, and patient declined to be included in the study.

Before AVF creation, all patients were clinically examined and Doppler ultrasonography was performed, and basal digital pressure (BDP) was measured by Laser Doppler in the limb of interest. The surgical intervention was performed through a standard technique (consisting of L-T brachiocephalic or L-T brachiobasilic fistula). At one and two months after the surgery, patients were reassessed clinically and by Doppler ultrasound, as well as with Laser Doppler.

Ultrasound evaluation of the AVF arm: The Doppler ultrasonography was performed using the NextGen LOGIQ™ ultrasound machine (PR China) with a broad-spectrum linear transducer of 7-15 MHz. Pre- and postoperatively, the vein diameters were measured in cross-section at the future anastomosis place, after applying a tourniquet to the upper third of the forearm or arm. The risk of undervaluing the size of the vein because of compression by the transducer was minimized by applying copious amounts of gel and a lower downforce. The ultrasound examination of the arteries and veins continued along its whole length, being complemented by colour Doppler sonography and spectral analysis. The size of the brachial artery was recorded in real time, grey scale, on longitudinal sections. The fistula blood flow was recorded according to Napoli recommendations[17].

Assessment of systolic DBP in AVF arm: BDP was measured in the vascular laboratory (Clinical Surgery 2) in Cluj-Napoca, Romania, using a Laser Doppler Perfusion Monitoring (LDPM) unit (Perimed's PeriFlux System 5000 version 1.70-1.79, Sweden) with the Perimed's Perisoft software for Windows programme (version 2.50 Järfälla-Stockholm, Sweden), after preliminary calibration of both LDPM and pressure measuring units. A warm environment was created, and the measurement was performed after approximately 10 min, during which the patient was asked to relax. BDP was recorded in all fingers of the hand corresponding to the limb planned to be used for AVF creation. The DBI was calculated by dividing the mean DBP to the smallest value of systolic blood pressure measured in the contralateral brachial artery, according to Sumner recommendations[18]. This index was calculated to permit digital pressure evaluation by eliminating the effect of systemic blood pressure during subsequent re-examinations. DBI was assessed preoperatively, at one and two months postoperatively. According to Valentine *et al*[19], a reduction in distal perfusion was documented if a >20 mmHg decrease in BDP was observed compared to the preoperative value.

Biochemical parameters: Blood samples (2 ml) were collected preoperatively, at one and two months after AVF creation. Calcium, phosphorus and BUN levels were measured using the Architect *c*4000 Clinical Chemistry analyzer (Abbott, Illinois, USA).

Statistical analysis: Qualitative variables were summarized as associated percentages and 95 per cent confidence intervals (95% CI, shown in brackets as lower limit and upper limit). CIs were calculated using a method similar to the one presented by Jäntschi and Bolboacă[20]. Quantitative variables were summarized as mean±standard deviation (SD) for data with normal distribution.

Comparisons between proportions were performed using the Z test for proportions at a significance level of 5 per cent. Comparisons of the sample means were performed using the Student's t test for independent samples at a significance level of 5 per cent. The variables measured at different time intervals (preoperatively, 1 month postoperatively and 2 months postoperatively) were compared by the paired two sample t test for means at a significance level of 1.7 per cent [$\alpha^*=\alpha/K$, where $K=k \cdot (k-1)/2$, k=number of determinations over time - in the present case 3]. A statistical significant difference was considered if $P<0.05$.

The association analysis between blood biochemical parameters and DBI was performed by Pearson correlation coefficient.

Results

A total of 115 patients with ESRD were examined clinically and by ultrasonography during the study period. Of these, 59 met the eligibility criteria for brachiocephalic or brachiobasilic AVF creation (cephalic and basilic vein diameters >1.7 mm; brachial artery diameter >2 mm), nine patients refused to be included in the study. Of the 50 patients who underwent

AVF creation, nine had non-functional AVF at one month after the surgery; so finally 41 patients were included in the current analysis.

All patients were of White Caucasian heritage, with a male:female ratio of 23:18. The difference in the proportion of man (56.1%) versus women (44%) was not significant. Their age ranged between 41 and 85 yr at the time of AVF creation. The baseline demographic characteristics and AVF type are shown in Table I. Of all patients included in the analysis, 12 (30%) were not in a haemodialysis programme and 29 (70%) were on haemodialysis through internal jugular catheter at the time of AVF creation. Of the patients on haemodialysis, 10 (24%) had an AVF on the same side with the new access and eight (20%) had an AVF on the contralateral arm, but these fistulas were non-functional.

The most common type of vascular approach was brachiocephalic AVF in 32 patients (78%, 95% CI: 63.5-90.2). Brachiobasilic AVF was performed in nine patients (22%, 95% CI: 9.8-36.5). None of the patients developed clinical symptoms of HAIDI during the conduct of the study.

Table I. Patient characteristics at baseline and arteriovenous fistula type

Category	Value (%)
Age (yr), mean±SD	62±11.26
Men	23 (56)
Women	18 (44)
Associated pathology	
Diabetes	16 (39.0)
Hypertension	36 (87.8)
Ischaemic heart disease	12 (29.3)
Peripheral artery disease	6 (14.6)
Aetiology of renal disease	
Diabetes	12 (29.3)
Chronic nephritis	20 (48.8)
Renal cancer	3 (7.3)
Polycystic disease	2 (4.9)
Kidney stones	2 (4.9)
Renovascular disease	1 (2.4)
Nephrotic syndrome	1 (2.4)
Arteriovenous fistula type	
Brachiocephalic	32 (78)
Brachiobasilic	9 (22)

Evaluation of BDP, DBI and blood vessels diameters: The preoperative mean BDP was 131.64±25.86 and significantly decreased to 93.15±32.14 and 94.53±32.90 mmHg at one and two months, respectively after AVF creation (P<0.001). No significant difference was observed between BDP values at one and two months. Reduction of BDP at one and two months postoperatively compared to preoperative value was >20 mmHg in 28 of 41 patients (68.29 %). When comparing the patients without previous dialysis access with the patients with ipsilateral haemodialysis access, no significant difference was observed between BDP preoperative values (131.87±33.65 vs. 131.51±24.83 mmHg, respectively). Similar results were obtained at one month (101.39±42.77 vs. 95.39±26.52 mmHg, respectively) and two months (104.95±25.06 vs. 105.67±24.94, respectively) postoperatively.

The mean DBI significantly decreased one month postoperatively, from 0.89±0.17 to 0.70±0.18 mm (P<0.001), and remained similar at two months postoperatively compared to one month (0.70±0.23 vs. 0.70±0.18 mm, respectively). When comparing the predialysis patients without previous dialysis access versus the patients with ipsilateral haemodialysis access, no significant difference in DBI was observed between preoperative values (0.87±0.27 vs. 0.91±0.10, respectively), one month (0.67±0.22 vs. 0.73±0.14, respectively) or two months (0.71±0.16 vs. 0.78±0.12, respectively) postoperative values.

From pre- to one and two month(s) after AVF creation, the mean brachial artery and cephalic/basilic vein diameter significantly increased, a significant increase was also observed between the diameters at one month versus two months. Taken separately, a significant increase of vein diameter between one month and two months postoperatively was observed for the cephalic vein only (Table II). The mean cephalic vein diameter increased with 3.38±1.90 mm at one month postoperatively and 4.27±2.46 mm at two months postoperatively, while the basilic vein diameter increased with 2.26±1.43 mm and 2.11±1.70 mm, respectively. The increase of the cephalic vein diameter was significantly higher compared to the increase of the basilic vein diameter at both one and two month(s) postoperative timepoints (P=0.05 and P=0.01, respectively).

Table II. Diameters of the cephalic and/or basilic veins and brachial artery used for arteriovenous fistula creation by timepoint

Diameter (mm)	n	Timepoints and comparisons of 1M post and 2M post versus pre (mean±SD)		
		Pre	1M post	2M post
Brachial artery	41	4.35±1.18	5.36±1.01***	5.54±1.18***
Cephalic/basilic vein	41	3.10±1.21	7.02±1.53***	7.72±2.25***,†††
Cephalic vein	32	3.83±1.35	7.21±1.52***	8.10±2.21***,†††
Basilic vein	9	4.08±1.59	6.33±1.42***	6.19±1.41**

P^{**}<0.01, ***<0.001 compared to respective pre values; †††P<0.001 compared to 1M Post values
AVF, arteriovenous fistula; SD, standard deviation; Pre, before AVF creation; 1M/1M Post, 1/2 month(s) after AVF creation

An increase in the AVF's flow was observed from 1154.02±643.41 ml/min at one month postoperatively to 1178.44±653.44 ml/min at two months postoperatively. However, this increase did not reach a significance. Three patients had high flow accesses (>2000 l/ml).

No significant correlation was observed between the percentage decrease of DBI at one and two months post-AVF creation and the difference between the brachial artery diameter at one month and two months, respectively, and preoperative values, between the diameter of the cephalic/basilic veins at one and two months, respectively, and preoperative values, and the flow of the AVF at one and two months postoperatively.

No significant difference of mean DBI decrease (difference between pre- and postoperative value) was observed between patients who were not enrolled in the dialysis programme at the time of AVF creation (n=12), those already on haemodialysis (n=29). The difference in the mean DBI between patients without previous access and those with previous ipsilateral access was not significant from pre to one month postoperatively (0.19±0.31 vs. 0.18±0.16, respectively).

Evaluation of calcium, phosphorus and blood urea nitrogen (BUN) levels: The association between preoperative calcium and phosphorus levels and the occurrence of digital pressure changes was analyzed by calculating the correlation between baseline calcium and phosphorus levels (Table III) and the difference between preoperative and one month post-operative DBI. No correlation was detected between baseline phosphorus level and DBI (r=0.015), neither between calcium and DBI changes (r=−0.05). The same association was assessed between preoperative BUN and DBI, but no correlation was observed (r=0.013) (Table III).

Table III. Blood biochemical parameters and correlation with digital brachial index (DBI) at baseline (n=41)

Biological parameter	Value (mean±SD)	Pearson correlation coefficient (r)
Serum phosphorus (mg/dl)	6.22±3.42	0.015
Total calcium (mg/dl)	8.45±1.07	−0.05
Urea nitrogen (mg/dl)	142.09±61.42	0.013

Discussion

Brachiocephalic fistulas are vascular access type procedures, in which hand ischaemia is the most commonly encountered complication[12]. Prior to the development of ischaemia clinical signs, a gradual decrease of BDP and DBI may be observed in patients who underwent brachial AVF creation. In our study, though a significant decrease of BDP from baseline to one and two months after AVF creation was observed, with a mean reduction in BDP >20 mmHg in 68 per cent of patients, no acute (within 24 h), subacute (within 1 month) or chronic (>1 month) forms of HAIDI[21,22] were recorded. The follow up period in our study was until two months after AVF creation, and it could be possible for some patients to develop ischaemia signs during further follow up. In a study conducted by Valentine *et al*[19], 14 (18%) patients with mean BDP reduction of 54 mmHg from pre- to three weeks after AVF creation developed ischaemia signs. In a study conducted by Papasavas *et al*[6], at a mean BDP of approximately 150 at baseline and 112 mmHg at one month after AVF creation, six patients (17%) developed ischaemia associated-symptoms. In terms of DBI, a significant decrease of 21.3 per cent was observed at one month after AVF creation compared to baseline DBI similar to that reported by Papasavas *et al*[6]. In our study, a percentage decrease of 22.2 per cent was recorded at two months after AVF creation. The postoperative mean DBI was 0.70±0.18 and none of the patients developed clinical signs of ischaemia. In the study conducted by Valentine *et al*[19], the postoperative mean DBI was 0.65±0.29 and 18 per cent patients (14 of 72) developed ischaemia symptoms. Papasavas *et al*[6] reported DBI values of 0.7 in patients without clinical signs of ischaemia and 0.4 in patients with clinical signs of ischaemia.

Following AVF creation, the patients' arteries undergo remodelling in response to increased parietal flow and pressure. This remodelling involves increasing the diameter of the vessel without arterial wall hypertrophy[23]. In our study, the brachial artery diameter increased significantly from 4.35±1.18 mm preoperatively to 5.36±1.01 mm at one month post after AVF creation. A failure to properly remodel arteries in diabetic patients or patients with atherosclerotic high load has been proposed as a cause of hypoperfusion[5]. In our group of patients, no significant relationship between the occurrence of digital pressure changes (evidenced by a significant decrease in DBI from baseline to 1 month and 2 months after AVF creation) and the degree of arterial remodelling was observed. This finding suggests that the change in diameter of the brachial artery cannot be regarded as an independent parameter in the development of distal hypoperfusion.

Following AVF creation, the deviation of a part of the arterial blood occurs at the arteriovenous anastomosis level towards the venous side, with low resistance circuit. It has been shown that the decreased pressure appears from approximately 20-25 cm proximal to the anastomosis[2,24,25]. Vascular resistance is inversely proportional to the diameter of the vessel. In our study, the vein diameter was increased at one month postoperatively, compared to preoperatively. In our study, no significant correlation was found between the degree of development of the vein and the decrease of DBI measured at one month or two months postoperatively. This can be explained by the development of collateral circulation that can replace blood flow to the periphery[11].

We found no significant link between decrease in digital pressure and fistula flow at one and two months after AVF creation. This result differs from those of similar studies[12]. This might be due to differences in the flow of fistulas of patients included in the studies. High-flow fistulas have been shown to increase the risk for hypoperfusion[11]. Other authors, however, using photoplethysmography for objectifying hypoperfusion, suggest that hypoperfusion is not influenced by low and medium fistula flows[12]. This phenomenon can be explained by the fact that only high flow rates (>2-2.5 l/min) cause changes in the systemic circulation. Vaes *et al*[26] found an increase in systolic or diastolic blood pressure after the temporary intraoperative clamping of the fistula, only in the case of high flow fistulas. In the same study, the systolic and diastolic blood pressure increase did not occur in patients with hypoperfusion phenomenon, these patients had low and medium flow fistulas.

No correlation was observed between DBI at baseline and the biochemical parameters changes (phosphorus, calcium and BUN). However, in patients on long-term follow up, assessment of these variables should be recommended, especially because in the ESRD, due to reduced calcium intake in the hypoproteic scheme, decreased active vitamin D and calcium ion binding by excess phosphate, hypocalcaemia may occur. This causes stimulation of parathyroid hormone (PTH) synthesis and parathyroid cell hyperplasia, ultimately leading to the appearance of secondary hyperparathyroidism. Arterial calcifications are commonly encountered in this syndrome[27], and their deposits can lead to the development of arterial stenosis of varying degrees and eventually to distal hypoperfusion. The relationship between mineral metabolism changes and the occurrence of venous and arterial calcification in patients with ESRD has been demonstrated by several authors[27-30]. Taken together, these studies have demonstrated a direct relationship between the level of phosphorus and serum calcium and increased cardiovascular mortality and thrombosis of AVFs.

Our study had several limitations. First, DBI was not measured in the contralateral arm because it was decided to compare postoperative DBI values versus preoperative DBI values of the same arm. We considered that this type of comparison would be more accurate for a long-term study (patients were followed up for two years after AVF creation) due to possible vascular pathologic changes (*e.g.* different level of calcifications, thrombosis and atherosclerotic plaques) that may occur overtime on one arm only. Comparison of DBI between the arm used for AVF creation and contralateral arm might have given us a more complete overview of the differences in digital pressure after AVF creation. Second, artery calcification was not assessed in the study because a very low number of patients were identified by ultrasonography as having scarce calcification signs in the artery of the hand used for AVF creation and none of the patients had clinical symptoms of ischaemia. Another study limitation was that PTH levels were not measured. As per routine clinical practice, PTH levels are measured only in case of high-grade calcifications detected in the arteries. As a few patients included in this analysis had minor calcification signs, it was decided not to include PTH levels in this analysis.

In conclusion, our findings suggest that the distal blood pressure decrease following AVF creation may not be influenced by the degree of arterial remodelling, vein diameter or fistula flow. In most of the cases, DBI reduction occurs within one month after AVF creation, with no further significant decrease during the second month. In uraemic patients, those with low levels of calcium ion and/or increased levels of serum phosphorus, no association between these biochemical parameters and distal pressure changes could be observed. For the routine clinical practice, preoperative measurement of DBI does not appear to be a reliable parameter for assessing potential HAIDI development after AVF creation.

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