Heparin use during dialysis sessions induces an increase in the antiangiogenic factor soluble Flt1

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ABSTRACT

Background. Soluble Flt1 (sFlt1) is a potent inhibitor of vascular endothelial growth factor, secreted mainly by the placenta, endothelial cells and monocytes. Increased sFlt1 serum levels correlate with endothelial dysfunction and cardiovascular complications in dialysis patients. However, the impact of dialysis by itself on sFlt1 serum levels remains unknown.

Methods. We assessed sFlt1 kinetics during dialysis and the impact of different dialysis techniques [high-flux haemodialysis (HD), haemodiafiltration (HDF)] and heparinization procedures on sFlt1 serum levels in 48 patients on regular dialysis.
INTRODUCTION

Cardiovascular disorders remain the leading cause of morbidity in patients with end-stage renal disease (ESRD), and account for roughly half the mortality in these patients [1, 2]. Chronic kidney disease (CKD) by itself, particularly ESRD, is an independent cardiovascular risk factor and is associated with endothelial dysfunction [3, 4]. Traditional cardiovascular risk factors explain only half of the cardiovascular mortality in ESRD patients [5]. Non-traditional risk factors have been identified in CKD/ESRD patients including various markers of inflammation (C-reactive protein, IL6, TNFα) [5–7] and asymmetric dimethyl arginine [8]. Recently, endothelial dysfunction and cardiovascular outcomes in CKD and ESRD patients have been linked to an increase in soluble Flt1 (sFlt1), an inhibitor of the vascular endothelial growth factor (VEGF) [9]. VEGF is the most potent growth factor for endothelial cells. Several types of VEGF receptors have been identified, the two main ones being VEGF-R1 and -R2. A circulating form of VEGF-R1, soluble Flt1 (sFlt1), (molecular weight 78 kDa) [10] is generated through an alternative splicing of VEGF-R1 transcript, but also, probably, from the cleavage of the membrane-bound form of VEGFR1 [11, 12]. sFlt1 is secreted mainly by monocytes, endothelial cells and placental cytotrophoblasts and binds and thus inhibits VEGF. Elevated levels of sFlt1 lead to functional VEGF deficiency, and promote an effective ‘antiangiogenic state’. The clinical importance of such a sFlt1-driven ‘antiangiogenic state’ has been illustrated by the association of elevated serum sFlt1 levels with pre-eclampsia [13]. More recently, Di Marco et al. [9] showed that sFlt1 contributes to endothelial dysfunction in patients with CKD. In their study, increased sFlt1 serum levels were correlated to the occurrence of cardiovascular events, particularly myocardial infarction and stroke.

Accumulating experimental data indicate that sFlt1 release may be promoted by inflammation mainly through complement activation (anaphylatoxin C5a) [14, 15]. ESRD is perceived as a state of chronic low-grade inflammation. Besides, haemodialysis (HD) procedures per se exacerbate inflammation, mainly through the contact of blood with materials (dialysis membranes and extracorporeal circuit elements) [16]. Even though significant progress has been achieved in order to increase the biocompatibility of HD material, release of inflammatory cytokines (IL-1, -6 and -8) still occurs during HD sessions with biocompatible membranes [17].

To date, no data regarding the impact of HD by itself on sFlt1 serum levels in ESRD patients have been reported. In the present study, we aimed to assess the impact of various dialysis procedures on the serum levels of sFlt1 in patients with ESRD.

MATERIALS AND METHODS

Patients and serum analysis

Forty-eight consecutive patients who have started long-time HD for more than 1 month and followed in our institution were included in the study. Their main clinical and biological characteristics are summarized in Table 1. Patients with acute infection, recent surgery or cardiovascular event or acute and profound anaemia (haemoglobin < 8 g/dL) were excluded from the study. Blood samples were drawn from patients on chronic HD (Department of Nephrology and Immunology, CHU de Nantes, France) before and 1, 15, 30 min and 1, 2 and 4 h after the start of a regular 4-h HD or haemodiafiltration (HDF) session. Blood samples before the session were drawn from the arterial needle prior to connecting arterial blood tubing, and all the others samples were drawn from the sample site on the arterial side. Non-heparin-based solution (TAUROLOCK®) was used in the central venous catheters locks. We also included as controls 20 healthy individuals, who underwent venesection. HD sessions were performed

Table 1. Clinical and biological characteristics of 48 patients on regular dialysis included in the study

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n = 48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>22 (46%)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>70 (20–89)</td>
</tr>
<tr>
<td>Time on dialysis (months)</td>
<td>48 (1–355)</td>
</tr>
<tr>
<td>Fistula/indwelling catheter</td>
<td>40 (83%)/8 (17%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>43 (90%)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>23 (48%)</td>
</tr>
<tr>
<td>Myocardial infarction/cerebral ischaemia</td>
<td>12 (25%)</td>
</tr>
<tr>
<td>Revascularization procedures</td>
<td>15 (31%)</td>
</tr>
<tr>
<td>Haemoglobin (g/dL)</td>
<td>10.8 (8–12.7)</td>
</tr>
<tr>
<td>CRP (mg/L)</td>
<td>10 (0–66)</td>
</tr>
<tr>
<td>Albuminaemia (g/L)</td>
<td>35.8 (25–46)</td>
</tr>
<tr>
<td>Phosphataemia (mmol/L)</td>
<td>1.3 (0.74–2.26)</td>
</tr>
<tr>
<td>Erythropoien use</td>
<td>45 (94%)</td>
</tr>
<tr>
<td>Renin–angiotensin system blockers</td>
<td>11 (23%)</td>
</tr>
<tr>
<td>Statin use</td>
<td>16 (33%)</td>
</tr>
</tbody>
</table>

CRP, C-reactive protein.
RESULTS

Circulating sFlt1 levels increase during a dialysis session

sFlt1 levels were slightly increased at baseline (mean 102 pg/mL; range: 32–237) compared with healthy controls (69 pg/mL; range: 28–168; P = 0.054) (Figure 1). In all patients, an additional increase in serum sFlt1 was noted at all time-points during high-flux HD or post-dilution HDF, starting as early as 1 min (1180 pg/mL; range: 71–6440; P < 0.001) and reaching a maximum at 15 min (2551 pg/mL; range: 194–6393; P < 0.001) after the start of HD. Serum sFlt1 remained higher compared with baseline levels at 30 min, 1 and 2 h after the start of HD, but decreased to baseline levels by 4 h (Figure 1).

Impact of the type of dialysis membrane on sFlt1 levels during HD

To assess the impact of the type of membrane on sFlt1 levels during HD, 10 consecutive patients underwent HD using successively PEPA-FDX or NEPHRAL 500 membranes, and sFlt1 serum levels were assessed at different time-points. Serum sFlt1 levels did not differ between the two types of membranes at all time-points (P = 0.5, paired t-test) (Figure 2).

Impact of dialysis techniques and/or heparin on sFlt1 levels during dialysis

In order to assess the impact of dialysis procedures on sFlt1 kinetics, 27 consecutive patients underwent successively high-flux HD and post-dilution HDF using the same membrane (PEPA-FDX) and sFlt1 serum levels were assessed at different time-points (Figure 3). Serum sFlt1 levels were significantly higher during HD compared with HDF at all time-points, particularly, at 15 min [2987 pg/mL (577–5655) for HD versus 888 pg/mL (344–2807) for HDF] (P = 0.01 t-paired test, for all time-points).

Human monocytes culture

Peripheral blood mononuclear cells (PBMC) were extracted from blood using Ficoll (Eurobio, Les Ulis, France) and monocytes were isolated using elutriation and cultured as previously described [18]. After stimulation for 30 min with TNFα (2 ng/mL), monocytes were incubated with serum (10%) or various reagents for a variable duration ranging from 30 min to 16 h. In some experiments, monocytes were treated for 1 h with GM 6001 (25 µM), a broad-spectrum inhibitor of the matrix metalloproteinases family (MMPinh) or with an anti-C5a human receptor (aC5aR) monoclonal antibody (10 µg/mL), before incubation with serum from HD patients.

Subsequently, cell supernatants were harvested, cell debris was removed by centrifugation and samples were stored at −20°C until further processing.

Real-time quantitative PCR for the detection of the four sFlt1 isoforms was performed as previously described [18].

Statistics

All values are means with values range indicated. Data were analysed using one-way ANOVA, paired t-test, and Spearman rank correlation using Prism software (version 4; GraphPad, La Jolla, CA, USA). The normal distribution of the data was confirmed using the Shapiro–Wilk’s test.
There were two main differences in our unit between these two dialysis modalities: on the one hand, the technique itself (HD versus HDF) and, on the other hand, the heparinization procedures. In order to test the respective roles of techniques and heparinization procedures, 11 consecutive patients underwent dialysis sessions with three different modalities: (i) a ‘conventional’ HD session (extracorporeal circuit rinsed with heparinized saline, UH 5000 UI/L, and LMWH used for maintenance anticoagulation),

(ii) a post-dilution HDF session (priming on line, with ultra-pure water, LMWH used for maintenance anticoagulation) and

(iii) a HD session during which the dialysis circuit was not rinsed with heparinized saline but pre-filled with ultra-pure water (no use of UH, LMWH used for maintenance anticoagulation).

LMWH dose was the same for each patient in the three modalities.

When the rinsing of the extracorporeal circuit with heparinized saline was avoided during an HD session (modality C), sFlt1 increase was blunted compared with ‘conventional’ HD [15 min sFlt1 peak: 920 pg/mL (415–1680) versus 3166 pg/mL (1474–5655), \( P < 0.001 \)], but was similar to the increase noted in a post-dilution HDF session [765 pg/mL (344–1319), \( P = \text{ns} \)] (Figure 3).

These findings suggested that heparin is a major driver of sFlt1 increase during dialysis. In order to test this hypothesis, the same 11 patients underwent a HD session during which the dialysis circuit was pre-filled with ultra-pure water but LMWH administration was delayed for 30 min until after the start of the session. sFlt1 increase was completely prevented during the first 30 min of dialysis. LMWH injection was followed by a significant and rapid increase in sFlt1 serum levels (§\( P < 0.01 \) versus all time-points except 1 h in modality A). In contrast, with modalities B, C and D, no increase in sFlt1 levels occurred during the dialysis session.
subsequently underwent a pre-dilutional HDF session without any use of heparin. sFlt1 serum levels remained unchanged compared with baseline levels during dialysis (Figure 4).

A heparin-coated membrane does not induce circulating sFlt1 levels increase

Finally, we assessed the effect of a heparin-coated membrane (EVODIAL®) on sFlt1 serum levels. Eight patients underwent a pre-dilutional HDF session, with standard dialysate concentrates (bicarbonate-based buffer/BitCart Select®, acetic acid-based concentrate/SelectBag® One) but without the use of either UH or LMWH. No increase in sFlt1 levels occurred during dialysis (Figure 4). Similarly, when these patients underwent an HD session, with EVODIAL® and a citrate-based dialysate (Citrasate®) without the use of either UH or LMWH, no increase in sFlt1 levels was noted.

Change in endothelial cells markers during a dialysis session

Next, we assessed whether the increase of sFlt1 levels was associated with any change in the levels of two markers of endothelial cell activation, sVCAM and soluble E-selectin during dialysis. No significant change in serum levels of sVCAM or E-selectin was detected (Supplementary Figure S1).

Effect of UH and LMWH on sFlt1 secretion by human monocytes in vitro

Our in vivo findings prompted us to test the effect of various types of heparin on sFlt1 release by monocytes. Monocytes from healthy donors (n = 4) and monocytes from HD patients drawn at t0 before the start of a HD session (n = 5) and at 30 min after the start of a heparin-free HD (n = 5) were incubated with UH at different doses (10 and 50 IU/mL) and LMWH (0.5, 5, 25 and 50 IU/mL) for 30 min, 2, 4, 8 and 16 h. No significant and reproducible increase in the release of sFlt1 by monocytes was detected at the various time-points, regardless of the type and dose of heparin or the source of monocytes (data not shown).

Effect of HD patients’ serum on sFlt1 secretion by human monocytes in vitro

Finally, we assessed the impact of HD patients’ serum, drawn before and during a ‘conventional’ HD session, on sFlt1 release by monocytes in vitro (Figure 5). Sera drawn between 1 and 30 min after the start of HD were not tested due to their high sFlt1 concentration that preclude any further assessment of sFlt1 release by monocytes in vitro. In order to correct for the sFlt1 present in sera drawn 1 h after the start of HD, these sera were incubated without monocytes for up to 16 h and residual sFlt1 levels assessed. Negligible levels of sFlt1 were detected after 16 h incubation [mean sFlt1: 16 pg/mL (7–20)]. Only the serum drawn 1 h after the start of HD induced a significant sFlt1 release by monocytes and only after 16 h incubation [mean sFlt1: 452 pg/mL (250–846) for serum t1h versus 181 pg/mL (73–132) for control serum] (P < 0.001). Inhibition of C5a receptor or metalloproteases involved in the cleavage of membrane-bound VEGFR1 did not alter sFlt1 release by monocytes (Figure 5).

DISCUSSION

Our data clearly show that heparin, and not dialysis by itself, induces a dramatic increase during dialysis in the serum levels of sFlt1, a potent antiangiogenic factor. During the first hour of a conventional heparin-based HD session, mean sFlt1 serum levels peaked at roughly 25–30 times their baseline levels, reaching values only detected in women with pre-eclampsia [13]. sFlt1 has been linked in most studies, to a worse maternal and fetal cardiovascular outcome. For instance in the previous study by Di Marco et al. [9], markers of endothelial dysfunction and the incidence of cardiovascular events in CKD/ESRD patients were correlated to a milder (2-fold the normal range), albeit chronic, increase in sFlt1 levels. In contrast, in the acute setting of myocardial infarction, an increase in sFlt1 was associated with an improved left ventricular function [19]. However, in the setting of chronic heart failure, increased sFlt1 correlated with disease severity and adverse outcomes [20]. Besides, in the peculiar population of patients on HD, an increase in sFlt1 was an independent risk factor for cardiac and all-cause mortality [21]. In a relatively limited number of dialysis patients, and in accordance with previously published data [22], we did not detect a significant increase during dialysis in two endothelial activation soluble markers, sVCAM and sE-selectin.
sE-selectin. However, one cannot exclude that the impressive and repeated (thrice weekly) increase in sFlt1 serum levels induced by heparin use during dialysis sessions may contribute in the short term to the impairment of VEGF-induced vasodilatation and in the long term to the impairment of endothelial repair [23] and thus to the high cardiovascular burden in ESRD patients. This point warrants further assessment in prospective long-term studies.

The introduction of UH and later of LMWH represented a key step in the improvement and thus the rapid development of dialysis [24]. HD is a unique situation that allows an in vivo assessment of the impact of heparin on sFlt1 release. Our data clearly indicate that heparin, and not dialysis by itself, is the main inducer of sFlt1 increase during HD sessions. When UFH or LMWH administration was avoided or delayed during an HD or a pre-dilutional HDF session, no significant increase in sFlt1 serum levels occurred. Our data are in accordance with recent reports on the impact of heparin on the release of sFlt1 by two of its main sites of production: the placenta and endothelium/vessel wall [25, 26]. In vitro, heparin induces sFlt1 release by placental explants through the shedding of the extracellular domain of membrane-bound Flt1. Heparins and the endogenous heparanase, an endo-β-D-glucuronidase, also induce the displacement of cell or heparan/sulphate-bound sFlt1 stored in the placenta and arterial wall [27]. In vivo, pregnant women and patients undergoing cardiac catheterization procedures, and receiving heparin, experience an increase in circulating sFlt1 levels [26]. However, this is the first demonstration of the impact of heparin on sFlt1 kinetics in dialysis patients, who unlike other types of patients, are repeatedly (thrice a week) and for several years, exposed to a dramatic heparin-induced increase in sFlt1 serum levels during dialysis.

As monocytes are the main secretors of sFlt1, one could assume a major role of these cells in the sharp increase in sFlt1 during HD session. The increase in sFlt1 serum levels started as early as 1 min after the beginning of the dialysis and therefore could be due to the early contact of blood components (monocytes) with the heparinized extracorporeal circuit, before the injection of LMWH, at least during a ‘conventional’ HD session. However, in vitro, LMWH and UH did not induce sFlt1 release by monocytes isolated from healthy control or HD patients. Our in vitro experiments only assessed the effect of heparin on sFlt1 release by circulating monocytes collected during an HD session. The fact that the experimental data in vitro do not confirm the in vivo results is clearly a limitation to our study. Our hypothesis that prior activation of monocytes through adhesion to the extracorporeal circuit is mandatory for an induction of sFlt1 release by heparins remains to be tested.

In contrast, LMWH systemic administration (on the arterial line) may affect both monocytes and endothelial cells release of sFlt1. Endothelial cells may also play a central role in the increase of sFlt1 serum levels during dialysis. The impact of heparin on sFlt1 release by endothelial cells/arterial wall has been previously documented in vitro [26, 27]. Therefore, LMWH administration on the arterial line is very likely to have an effect on endothelial cells and (subsequently) on sFlt1 increase. Secondly, the absence of any increase in sFlt1 levels during dialysis with a heparin-coated membrane, EVODIAL®, also argues for a role of endothelial cells. Heparin on the surface of this membrane is irreversibly fixed by multiple ionic bonds and thus is not released in the bloodstream. The absence of any increase in sFlt1 levels with the use of this membrane suggests that the systemic administration of heparin is crucial for the induction of sFlt1 release by endothelial cells. However, one cannot exclude an effect of systemic heparin on monocytes or a reduced heparin-induced activation of monocytes at the contact of the EVODIAL membrane.

Besides, our data indicate that heparin-based dialysis not only induces a sharp increase of sFlt1 during an HD session, but also contributes to the maintenance of the previously documented low-grade chronic increase of sFlt1 in these patients [9]. Serum drawn after 1 h of HD session, but not serum drawn before a HD session, induced a late release of sFlt1 by human monocytes. This effect was mediated through an increase in the synthesis of sFlt1 but not through a cleavage of the membrane-bound Flt1 and was independent of the complement anaphylatoxin C5a. sFlt1 release was not mediated by the LMWH contained in the patients’ serum as heparin by itself did not induce any significant release of sFlt1 by monocytes. The nature of the mediators which induce this sFlt1 increase remains unknown and is currently being investigated.

Our findings have several important implications for the management of ESRD patients undergoing HD. Firstly, the evaluation of the efficiency and biocompatibility of membranes and dialysis procedures has been traditionally based on their potential to induce the activation of the coagulation and complement cascade, the release of various inflammatory cytokines and the clearance of small and medium-size molecules [28]. sFlt1 may be an additional pertinent parameter for the evaluation of dialysis biocompatibility. For instance, our data suggest that a higher efficacy and biocompatibility of membranes is expected with HMWH (citrate-based HD or pre-dilutional heparin-free HDF) on sFlt1 kinetics and most importantly long-term cardiovascular events remain to be evaluated. In the present study, we simply used Citrasate® in association with EVODIAL® as a way to achieve a totally heparin-free HD session. However, the concentration of Citrasate® was low, and it remains unknown whether a higher
dose of citrate (as in regional citrate anticoagulation) for a longer heparin-free session would affect sFlt1 secretion.

In conclusion, heparin-based dialysis induces a major sFlt1 release and therefore may exacerbate the sFlt1-associated anti-angiogenic state in ESRD patients and thus aggravates their endothelial dysfunction and cardiovascular burden. This should be taken into account for the assessment and establishment of optimal dialysis procedures.

SUPPLEMENTARY DATA

Supplementary data are available online at http://ndt.oxfordjournals.org.

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CONFLICT OF INTEREST STATEMENT

None declared. The results presented in this paper have not been published previously in whole or part, except in abstract form.

(See related article by Di Marco et al. Soluble Flt-1 release response to heparin use: implications for dialysis patients? Nephrol Dial Transplant 2014; 29: 1112–1115.)

REFERENCES

24. Davenport A. What are the options for anticoagulation needs in dialysis for patients with heparin-induced thrombocytopenia? Semin Dial 2011; 24: 382–385

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