The following full text is a publisher's version.

For additional information about this publication click this link.
http://hdl.handle.net/2066/108098

Please be advised that this information was generated on 2019-10-26 and may be subject to change.
Hepcidin-25 in Chronic Hemodialysis Patients Is Related to Residual Kidney Function and Not to Treatment with Erythropoiesis Stimulating Agents

Neelke C. van der Weerd1,2*, Muriel P. C. Grooteman1,3, Michiel L. Bots4, Marinus A. van den Dorpel5, Claire H. den Hoedt5,6, Albert H. A. Mazairac6, Menso J. Nube1,3, E. Lars Penne1,6, Carlo A. Gaillard1, Jack F. M. Wetzels7, Erwin T. Wiegerinck8,9, Dorine W. Swinkels8,9, Peter J. Blankestein8,9, Piet M. ter Wee1,3

CONTRAST investigators

1 Department of Nephrology, VU Medical Center, Amsterdam, The Netherlands, 2 Department of Nephrology, Academic Medical Center, University of Amsterdam, Amsterdam, The Netherlands, 3 Institute for Cardiovascular Research VU Medical Center (ICaR-VU), VU Medical Center, Amsterdam, The Netherlands, 4 Julius Center for Health Sciences and Primary Care, University Medical Center Utrecht, Utrecht, The Netherlands, 5 Department of Internal Medicine, Maasstad Hospital, Rotterdam, The Netherlands, 6 Department of Nephrology, University Medical Center Utrecht, Utrecht, The Netherlands, 7 Department of Nephrology, Radboud University Nijmegen Medical Center, Nijmegen, The Netherlands, 8 Department of Laboratory Medicine, Laboratory of Genetic, Endocrine and Metabolic Diseases, Radboud University Nijmegen Medical Center, Nijmegen, The Netherlands, 9 Hepcidinanalysis.com, Radboud University Nijmegen Medical Center, Nijmegen, The Netherlands

Abstract

Hepcidin-25, the bioactive form of hepcidin, is a key regulator of iron homeostasis as it induces internalization and degradation of ferroportin, a cellular iron exporter on enterocytes, macrophages and hepatocytes. Hepcidin levels are increased in chronic hemodialysis (HD) patients, but as of yet, limited information on factors associated with hepcidin-25 in these patients is available. In the current cross-sectional study, potential patient-, laboratory- and treatment-related determinants of serum hepcidin-20 and -25, were assessed in a large cohort of stable, prevalent HD patients. Baseline data from 405 patients (62% male; age 63.7±13.9 [mean SD]) enrolled in the CONvective TRANsport STudy (CONTRAST; NCT00205556) were studied. Predialysis hepcidin concentrations were measured centrally with matrix-assisted laser desorption/ionization time-of-flight mass spectrometry. Patient-, laboratory- and treatment related characteristics were entered in a backward multivariable linear regression model. Hepcidin-25 levels were independently and positively associated with ferritin (p<0.001), hsCRP (p<0.001) and the presence of diabetes (p = 0.02) and inversely with the estimated glomerular filtration rate (p = 0.01), absolute reticulocyte count (p = 0.02) and soluble transferrin receptor (p<0.001). Men had lower hepcidin-25 levels as compared to women (p = 0.03). Hepcidin-25 was not associated with the maintenance dose of erythropoiesis stimulating agents (ESA) or iron therapy. In conclusion, in the currently studied cohort of chronic HD patients, hepcidin-25 was a marker for iron stores and erythropoiesis and was associated with inflammation. Furthermore, hepcidin-25 levels were influenced by residual kidney function. Hepcidin-25 did not reflect ESA or iron dose in chronic stable HD patients on maintenance therapy. These results suggest that hepcidin is involved in the pathophysiological pathway of renal anemia and iron availability in these patients, but challenges its function as a clinical parameter for ESA resistance.


Editor: Leighton R. James, University of Florida, United States of America

Received February 29, 2012; Accepted May 26, 2012; Published July 13, 2012

Copyright: © 2012 van der Weerd et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Funding: The Dutch CONvective TRANsport STudy is financially supported by a grant from the Dutch Kidney Foundation (Nierstichting Nederland, grant C02.2019) and unrestricted grants from Fresenius Medical Care (The Netherlands) and Gambro Lundia AB (Sweden). Additional support for CONTRAST was received from the Dr. E.E. Twiss Fund, Roche Netherlands; the International Society of Nephrology/Baxter Extramural Grant Program; the Dutch Organization for Health Research and Development (ZonMW, grant 17088.2802); and for this particular study from Amgen BV Netherlands. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: DWS is a co-founder and Medical Director of the “Hepcidinanalysis.com” initiative, which aims to serve the scientific and medical community with high-quality hepcidin-25 measurements (www.hepcidinanalysis.com). The other authors have declared that no competing interests exist. Furthermore, the main study was supported by funding from several commercial sources (Fresenius Medical Care, Gambro Lundia AB (Sweden), Roche Netherlands, Baxter Netherlands and Amgen BV Netherlands). This does not alter the authors adherence to all the PLoS ONE policies on sharing data and materials.

* E-mail: n.c.vanderweerd@amc.uva.nl

† Membership of the CONTRAST investigators is provided in the Acknowledgments.

Introduction

Hepcidin is a key regulator of iron homeostasis in humans. It induces internalization and degradation of ferroportin, which is a cellular iron exporter on enterocytes, macrophages and hepatocytes [1,2]. Hence, hepcidin reduces iron absorption from the gut and iron release from reticuloendothelial and hepatocyte stores. The bioactive form is hepcidin-25, a mainly protein-bound amino acid of 2.8 kD, whereas hepcidin-20 and hepcidin-22 are its isomers with unknown biological function [2,3]. The expression of hepcidin is regulated in response to iron administration, erythropoietic demand, hypoxia and inflammatory signals [2,4].

Cite this article as:
Hepcidin is excreted with the urine. In patients with chronic kidney disease (CKD), serum levels of the active hepcidin-25 and its isoforms are increased [5,6]. In patients with end stage renal disease (ESRD) on dialysis, even higher levels of hepcidin have been observed [5,6]. Hepcidin is the intermediary between available iron stores on the one hand, and erythropoiesis on the other hand. Furthermore, it has been suggested that hepcidin is an important tool to predict the response to erythropoiesis stimulating agents (ESA) [7,8,9]. Therefore, hepcidin might be useful to assess the functional iron availability in patients with renal failure as high levels might indicate a blockade of iron release from its stores [10].

In several studies, patient-, laboratory- and treatment characteristics of CKD and ESRD patients have been related with hepcidin levels. Many studies have shown a relation between ferritin levels and hepcidin, both in CKD [5,6,9,11] and in hemodialysis (HD) patients [5,12,13,14,15]. Furthermore, studies in CKD and HD patients have shown associations with hepcidin and various other parameters such as residual kidney function (RKF) [6,11,16]. ESA dose [11] and markers of inflammation including C-reactive protein (CRP), tumor necrosis factor \(\alpha\) (TNF-\(\alpha\)) and interleukin-6 (IL-6) [7,15]. In these studies, hepcidin has been measured with different techniques, mainly competitive immunoassays and mass spectrometry (MS) based methods, impeding direct comparisons [3,17,18]. Furthermore, most studies on hepcidin in HD patients included a limited number of patients, precluding multivariate statistics.

In the current study, patient-, laboratory- and treatment characteristics that are associated with hepcidin levels are evaluated with a state-of-the-art hepcidin assay in a prospective cohort of over 400 chronic HD patients, included in the CONvective TRAnsport STudy (CONTRAST).

**Materials and Methods**

**Patients and Study Design**

Baseline data from patients enrolled in the CONTRAST study (NCT00205556) were used. The rationale and the design of the CONTRAST study have been described before [19]. In short, prevalent HD patients were recruited from 2004 until 2010 and randomized to either continue treatment with low flux HD, or treated with either polysulfone (PS) or polyarylethersulfone (PAES) low-flux dialyzers with a UF coefficient varying between 10 and 21 mL/mmHg/l and a surface area from 1.3 to 2.2 m²: F6HPS, F7HPS, F8HPS and F10HPS (Fresenius Medical Care, Bad Homburg, Germany) and Polyflux 14 L, 17 L and 21 L (Gambro Corporation AB, Lund, Sweden). Dialysis was performed with ultrapure dialysis fluids, containing less than 0.1 colony forming units per mL and less than 0.03 endotoxin units per mL.

Routine patient care and prescription of medication was practiced according to the opinion of the attending nephrologist and based on the Quality of Care Guidelines of the Dutch Federation of Nephrology. The Dutch Quality of Care Guideline on anemia management was derived from the European Best Practice Guidelines [21] and the KDOQI guidelines [22,23,24]. ESA and iron supplements were administered via the venous bloodstream at the end of a dialysis session. Decisions on dose changes and the timing of these changes were made according to the opinion of the treating nephrologist.

**Laboratory Protocol**

Predialysis blood samples were drawn and routine laboratory assessments were analyzed in the local hospitals by standard laboratory techniques. The total iron-binding capacity (TIBC) was considered to represent serum transferrin level [25] and the transferrin saturation ratio (TSAT) was either provided by the local laboratory or calculated as serum iron divided by the TIBC. Hepcidin, soluble transferrin receptor (sTfR), hsCRP and IL-6 measurements were preformed centrally. For this purpose, predialysis blood samples were centrifuged at 1500 g and 4°C for 10 minutes and stored at ~80°C.

Serum hepcidin-20 and -25 measurements were centrally performed by a validated combination of weak cation exchange (WCX) bead-based hepcidin enrichment followed by time-of-flight mass spectrometry (WCX-TOF-MS) [17]. For the quantification of hepcidin in serum, an internal standard (synthetic hepcidin-24, Peptide International Inc., Louisville, KY, USA) was used [26]. Peptide spectra were generated on a Microflex LT matrix-enhanced laser desorption/ionisation (MALDI)-TOF-MS platform (Bruker Daltonics GmbH, Bremen, Germany). Serum hepcidin-20 and -25 concentrations were expressed as nmol/L and the lower limit of detection of this method was 0.5 nmol/L. For hepcidin-25, the intra-assay coefficients of variation (CV) were 3.7% at 7.9 nmol/L, 2.3% at 13.4 nmol/L, and 2.2% at 3.1 nmol/L. The inter-assay CV were 9.1% at 7.8 nmol/L and 3.9% at 12.9 nmol/L [17]. This method enables the specific measurement of the hepcidin isoforms [hepcidin-25, hepcidin-22 and hepcidin-20] [17] and has been described before in CKD and HD patients [5]. It is an update of a previous method performed by the same laboratory [26,27]. sTfR (mg/L) was measured immunonephelometrically on a BN II System (Dade Behring Marburg GmbH, Marburg, Germany). hsCRP (mg/L) was measured with a particle-enhanced immunoturbidimetric assay on a Roche Hitachi analyzer (Roche Diagnostics GmbH, Mannheim, Germany) with a lower quantification limit of 0.1 mg/L and the study was conducted in accordance with the Declaration of Helsinki and was approved by a central medical ethics committee and by all local medical ethics review boards. Written informed consent was obtained from all patients prior to enrolment (File S1). Patients provided informed consent for storage of blood samples for later analysis.

**Treatment Protocol**

Included patients were stable for at least two months with a minimum dialysis spKt/V urea of 1.2 per treatment and they were treated with either polysulfone (PS) or polyarylethersulfone (PAES) low-flux dialyzers with a UF coefficient varying between 10 and 21 mL/mmHg/l and a surface area from 1.3 to 2.2 m²: F6HPS, F7HPS, F8HPS and F10HPS (Fresenius Medical Care, Bad Homburg, Germany) and Polyflux 14 L, 17 L and 21 L (Gambro Corporation AB, Lund, Sweden).
Table 1. Patient and treatment characteristics and laboratory parameters.a

<table>
<thead>
<tr>
<th>Patient characteristics</th>
<th>N = 405</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male gender – no. (%)</td>
<td>252 (62)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>63.7 ±13.9</td>
</tr>
<tr>
<td>Caucasian race – no. (%)</td>
<td>333 (82)</td>
</tr>
<tr>
<td>Dialysis vintage (years)</td>
<td>1.8 (0.9–3.6)</td>
</tr>
<tr>
<td>Cause of renal failure - no. (%)</td>
<td>vascular</td>
</tr>
<tr>
<td>- diabetes mellitus</td>
<td>63 (16)</td>
</tr>
<tr>
<td>- tubulointerstitial nephritis/glomerulo-nephritis/multisystem disease</td>
<td>96 (24)</td>
</tr>
<tr>
<td>- cystic disease</td>
<td>28 (7)</td>
</tr>
<tr>
<td>- other/unknown</td>
<td>87 (21)</td>
</tr>
<tr>
<td>Diabetes mellitus – no. (%)</td>
<td>85 (21)</td>
</tr>
<tr>
<td>History of cardiovascular disease – no. (%)</td>
<td>177 (44)</td>
</tr>
<tr>
<td>Current smoker – no. (%)</td>
<td>81 (20)</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>71.7 ±14.6</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>142 ± 18</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>73 ± 11</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.0 ±4.8</td>
</tr>
<tr>
<td>Residual diuresis – no. (%)</td>
<td>230 (57)</td>
</tr>
<tr>
<td>eGFR (ml/min/1.73 m²)</td>
<td>2.6 (1.2–5.1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment characteristics</th>
<th>N = 405</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment frequency 3x/week – no. (%)</td>
<td>375 (93)</td>
</tr>
<tr>
<td>Treatment time (min)</td>
<td>227 ±23</td>
</tr>
<tr>
<td>Dialysis access – no. (%)</td>
<td>298 ±39</td>
</tr>
<tr>
<td>- fistula</td>
<td>339 (84)</td>
</tr>
<tr>
<td>- graft</td>
<td>56 (14)</td>
</tr>
<tr>
<td>- central catheter</td>
<td>10 (2)</td>
</tr>
<tr>
<td>spKt/V (per dialysis)</td>
<td>1.39 ±0.20</td>
</tr>
<tr>
<td>Dialyzer – no. (%)</td>
<td>246 (61)</td>
</tr>
<tr>
<td>- polysulfone</td>
<td>147 (37)</td>
</tr>
<tr>
<td>- polycrylethersulfone</td>
<td>12 (3)</td>
</tr>
<tr>
<td>Prescription of ESA- no. (%)</td>
<td>364 (90)</td>
</tr>
<tr>
<td>Type of ESA – no. (%)</td>
<td>254 (70)</td>
</tr>
<tr>
<td>- darbepoetin α</td>
<td>110 (30)</td>
</tr>
<tr>
<td>- epoetin α/β</td>
<td>8.9 (6.0–15.4)</td>
</tr>
<tr>
<td>ESA dose (DDD/week)</td>
<td>300 (74)</td>
</tr>
<tr>
<td>Use of iron replacement therapy – no. (%)</td>
<td>100 (50–100)</td>
</tr>
<tr>
<td>Iron dose (mg/week)</td>
<td>215 (53)</td>
</tr>
<tr>
<td>Preservation of RAS inhibitors – no. (%)</td>
<td>203 (50)</td>
</tr>
<tr>
<td>Laboratory parameters</td>
<td></td>
</tr>
<tr>
<td>Hemoglobin (g/dL)</td>
<td>11.9 ±1.3</td>
</tr>
<tr>
<td>Hematocrit</td>
<td>0.36 ±0.04</td>
</tr>
<tr>
<td>MCV (fl)</td>
<td>94.9 ±6.2</td>
</tr>
<tr>
<td>Reticulocytes (x10⁹/L)</td>
<td>65.3 ±30.5</td>
</tr>
<tr>
<td>Ferritin (ng/mL)</td>
<td>378 (211–631)</td>
</tr>
</tbody>
</table>

Table 1. Cont.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>N = 405</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSAT (%)</td>
<td>24.3 ±12.4</td>
</tr>
<tr>
<td>sTfR (mg/L)</td>
<td>1.58 (1.24–2.11)</td>
</tr>
<tr>
<td>Cholesterol (mg/dL)</td>
<td>143.1 ±38.7</td>
</tr>
<tr>
<td>Albumin (g/dL)</td>
<td>3.6 ±0.5</td>
</tr>
<tr>
<td>hsCRP (mg/L)</td>
<td>3.95 (1.38–10.41)</td>
</tr>
<tr>
<td>IL-6 (pg/mL)</td>
<td>2.06 (1.21–3.82)</td>
</tr>
<tr>
<td>Hepcidin-20 (nM)</td>
<td>6.3 (3.9–9.3)</td>
</tr>
<tr>
<td>Hepcidin-25 (nM)</td>
<td>13.8 (6.6–22.5)</td>
</tr>
</tbody>
</table>

*aValues represent mean ± SD, median (interquartile range) or proportion (%).
*bWeight after dialysis (dry weight) defined as the mean of three consecutive values.
*cMean of pre- and post-dialysis blood pressure of three consecutive dialysis sessions.
*dDefined as >100 mL per day.
*eGFR (estimated glomerular filtration rate) calculated as mean of creatinine and urea clearance in 24 h urine collection adjusted for body surface area, exclusively in patients with residual diuresis.
*fIn patients on ESA therapy.
*gIn patients on iron therapy.
*Reference value: 0.76–1.76 mg/L (Dade Behring Marburg GmbH, Marburg, Germany).
*Reference value: 0.76–1.76 mg/L (Dade Behring Marburg GmbH, Marburg, Germany).
*Reference value: 0.76–1.76 mg/L (Dade Behring Marburg GmbH, Marburg, Germany).
*Reference value: 0.76–1.76 mg/L (Dade Behring Marburg GmbH, Marburg, Germany).
*Reference value: 0.76–1.76 mg/L (Dade Behring Marburg GmbH, Marburg, Germany).
*Reference value: 0.76–1.76 mg/L (Dade Behring Marburg GmbH, Marburg, Germany).
*Reference value (median [95% range]): men 65–69 years 5.3 (<0.05–13.9); women 65–69 years 4.9 (<0.05–14.2) [29].
*Conversion factors for units: hemoglobin in g/dL to mmol/L, 0.62; cholesterol in mg/dL to mmol/L, 0.026; albumin in g/dL to g/L, x 10; no conversion necessary for ferritin in ng/ml to µg/L.
*BMI = body mass index; ESA = erythropoiesis stimulating agents; RAS = renin angiotensin system; TSAT = transferrin saturation ratio; sTfR = soluble transferrin receptor; PTH = parathyroid hormone; hsCRP = high sensitive c-reactive protein; IL-6 = interleukin-6.
*IL-6 = interleukin-6.
*doi:10.1371/journal.pone.0039783.t001

Data Collection

Data on demography, cause of renal failure, history of cardiovascular disease (CVD), diabetes mellitus (DM), type of vascular access, dialysis vintage and treatment parameters were collected, as well as medication use. ESA was prescribed as epoetin α or β (Eprex® or Neorecormon® respectively, IU) or darbepoetin α (Aranesp®, µg) and expressed as a dose per week. To compare the different types of ESA, prescribed dosages were converted to daily defined doses (DDD), using conversion factors as provided by the World Health Organization (WHO) Drug Classification (http://www.whocc.no/atc_ddd_index/). For darbepoetin α (ATC code B03XA02), DDD is 4.5 µg and for epoetin α and β (ATC code B03XA01), DDD is 1000 IU. All patients on iron therapy used iron sucrose (Venofer®, mg/week).

RKF was defined as a urine production of >100 mL/d. In patients with RKF, the eGFR (estimated glomerular filtration rate) was calculated as the mean of creatinine and urea clearance in a 24 h urine collection, adjusted for body surface area [28].
Hepcidin-25 in Chronic Hemodialysis Patients

Statistical Analysis

Variables were reported as proportions or means ± standard deviation (SD), or medians with 25th–75th percentiles when appropriate. The relation between hepcidin-20 and hepcidin-25 was evaluated with a Spearman’s correlation test. All patient characteristics, laboratory parameters and treatment characteristics listed in table 1, were considered as possible determinants of hepcidin-25. First, relations between these determinants and hepcidin-25 were studied using a backward multivariable linear regression model with a p-value <0.15 as a cut-off level. Subsequently, the determinants that were related with Hecpidin-25 (with a p-value <0.15) were entered in a second multivariable regression model. In this second regression model, a double sided p-value <0.05 was considered statistically significant. The natural logarithm of hepcidin-25 (ln-hepcidin-25) was applied as the dependent variable in all regression models since the distribution of hepcidin-25 was positively skewed. The regression coefficients (B) were retransformed into percentages of change in hepcidin-25 by using the formula ($e^B-1$)×100, which means that for each increment in the determinant, hepcidin-25 changed with the specified percentage. Additionally, in a separate analysis, all regression models were adjusted for participants center to correct for local policies concerning anemia management and timing of ESA and iron administration and blood withdrawal.

To evaluate whether the relation between a determinant (e.g. hsCRP) and hepcidin-25 was modified by a second determinant (e.g. ferritin), the possibility of effect modification was explored by adding an interaction term (e.g. hsCRP x ferritin) to the multivariable regression model. If this interaction term turned out to be significant (p<0.05), the relation between the determinant and hepcidin-25 was analyzed separately in each stratum of the second determinant.

Statistical analyses were performed with PASW software (version 18.0, SPSS inc. Headquarters, Chicago, Illinois, US).

Results

Blood samples from 405 patients were available. All patient and treatment characteristics and laboratory parameters are listed in table 1 (baseline characteristics of the total CONTRAST cohort [n = 714] are listed in table S1). Mean (± SD) age of the patients was 63.7±13.9 years and 62% was male. Hepcidin-20 and hepcidin-25 were highly correlated (r = 0.76; p<0.001; figure 1). In this section, results for hepcidin-25 are presented. In analyses with hepcidin-20 as an outcome parameter, similar results were obtained (data not shown).

Multivariable Regression Analysis

In table 2, all determinants of hepcidin showing a p-value <0.15 in the backward multivariable linear regression model are listed. In the final model (R2 = 0.49), ferritin, hsCRP and the presence of diabetes mellitus showed a positive relation with hepcidin-25, whereas male gender, eGFR and sTfR had an inverse relation. Of note, no relation between hepcidin-25 and the weekly ESA dose and the administration of iron supplements was observed. Adjustment for participating center did not change the results (data not shown).

Interaction between Determinants

The relation between hsCRP and hepcidin-25 was modified by the ferritin level, as the interaction term (hsCRP x ferritin) was highly significant (p<0.001). This relation persisted after adjustment for other determinants of hepcidin-25. As depicted in figure 2, the relation between ferritin and hepcidin-25 was present irrespective of the level of inflammation (lowest hsCRP tertile: B = 0.020 per 10 ng/mL; 95%CI -0.015 to 0.026; p<0.001; middle hsCRP tertile: B = 0.014 per 10 ng/mL; 95%CI 0.010 to 0.018; p<0.001; highest hsCRP tertile: B = 0.015 per 10 ng/mL; 95%CI 0.010 to 0.020; p<0.001). In fact, the relation between hsCRP and hepcidin-25 was present in all three tertiles of ferritin (lowest tertile: B = 0.020 per mg/L; 95%CI −0.010 to 0.030; p<0.001; middle tertile: B = 0.009 per mg/L; 95%CI 0.000 to 0.018; p=0.055; highest tertile: B = 0.007 per mg/L; 95%CI 0.001 to 0.013; p = 0.034).

No interaction between hemoglobin level and ESA dose on hepcidin-25 levels was observed as the interaction term (ESA dose X hemoglobin) was not statistically significant (p = 0.588). The absence of a relation between those parameters is readily apparent from figure 3.

Discussion

In this cross-sectional study in a cohort of stable prevalent HD patients, hepcidin-25 levels were shown to be independently and positively associated with iron stores (as reflected by ferritin levels), inflammation (hsCRP) and the presence of diabetes, and inversely with erythropoiesis (sTIR and reticulocyte count), residual kidney function (eGFR) and male gender. Of note, no relations between hepcidin-25 and either ESA dose or iron supplementation were observed.

In our study, ferritin was the strongest determinant of hepcidin, which has been well established before in healthy controls [29], CKD patients [5,6,9,11] and in patients with ESRD treated with HD and peritoneal dialysis [5,12,13,14,15]. Notably, the studies in HD patients included mostly low patient numbers. As can be seen from figure 2, the relation between hepcidin-25 and ferritin was present irrespective of the level of inflammation. However, whether hepcidin is upregulated in response to increased ferritin levels cannot be concluded from our study.

sTIR has proven to be a valuable tool to assess bone marrow erythropoietic activity and iron stores in HD patients treated with ESA [30,31]. However, it could not predict a response of intravenous iron administration on the hemoglobin level [32]. In our study, an inverse association between either sTIR and reticulocyte count, and hepcidin levels was observed, after
multivariable adjustments. Whether low hepcidin levels enhance erythropoiesis, or whether increased bone marrow erythropoietic activity suppresses expression of hepcidin, cannot be concluded from this cross-sectional study.

We showed a strong association between hepcidin-25 and hsCRP, but not with IL-6. Several studies have demonstrated a relation between CRP [5,7,15,33] or IL-6 [7,13] in small groups of chronic HD patients, whereas others did not [14]. The explana-
tion for the association between hepcidin-25 and hsCRP, and not IL-6, is not readily apparent, especially as transcription of hepatic hepcidin is activated by binding of IL-6 to its receptor complex [1]. However, in a murine and human model investigating various factors associated with hepcidin expression, the role of IL-6 was limited [34]. Furthermore, the IL-6 assay used in our study showed a wide inter-assay variability, especially in the lower range. This could have resulted in less accurately measured values of IL-6 as compared to hsCRP, and hence less precision in the estimation.

We are the first to report an independent association between eGFR and both the active hepcidin-25 and the inactive isoform hepcidin-20 in HD patients. As we used a mass-spectrometry assay that specifically measures hepcidin-25, our results indicate that the observed association between eGFR and hepcidin-25 was not due to the concurrent measurement of inactive isoforms. To date, studies on the association between eGFR and hepcidin levels in CKD patients have been conflicting [5,6,11,35]. Low hepcidin levels (measured with a radioimmunoassay) were reported in HD and PD patients with residual diuresis [16], but RKF was not quantified in that study. Whether the high hepcidin levels in chronic HD patients were exclusively caused by decreased renal clearance, or whether other mechanisms are involved, cannot be concluded from our data.

In our study population, hepcidin-25 levels were significantly lower in men as compared to women. This can be explained by the fact that most women in our study will be post-menopausal, in whom higher hepcidin levels have been demonstrated [29]. Furthermore, we showed that diabetic patients had higher hepcidin levels. In one study, diabetic patients had higher levels of hepcidin than healthy age-matched controls, although this relation was not adjusted for possible confounders [36].

Interestingly, we did not observe an interaction between ESA dose and hemoglobin levels in relation to hepcidin-25 as has been demonstrated before by Ashby et al [11]. Therefore, it appears that hepcidin, measured with a mass spectrometric assay in chronic HD patients on maintenance therapy with ESA, is not a marker of ESA resistance. Whether hepcidin-25 can predict an ESA response, as has been shown in patients with the cardio-renal syndrome [9], cannot be concluded from our cross-sectional data. Nevertheless, in a study in 24 HD patients, hepcidin levels of ESA responsive patients did not differ from those who were ESA resistant [12], which is in accordance with our results.

Concerning iron supplementation in HD patients, various effects of iron loading on hepcidin levels have been reported [14,37,38]. We did not observe a relationship between hepcidin and iron supplementation, which can be explained by the fact that patients in our study received maintenance iron therapy instead of a (single) loading dose. Recently, it was shown that hepcidin-25 levels did not predict a response to the administration of intravenous iron supplementation in HD patients on ESA maintenance therapy [38]. Hence, it appears that hepcidin is more a marker of iron stores than a predictor of the effect of iron therapy.

A number of studies showed that hepcidin levels could be lowered over a single HD session [13,15,39], although concentrations were back to baseline only one hour after the treatment [13]. Lowering of hepcidin by HD can be partly explained by appearance of (low) levels of hepcidin in the ultrafiltrate [5,16]. In addition, it has been shown that hepcidin can attach to the membrane of the dialyzer [5], which can be explained by the amphipathic and protein-bound structure of hepcidin [2]. Prospective research is needed to draw any conclusions on the effect of different dialyzers on hepcidin-levels.

**Limitations and Strengths**

Our study is limited by its cross-sectional design, which impedes assessing causal relationships. Furthermore, a specific treatment
protocol for ESA and iron administration and timing of blood sampling was not provided. We tried to compensate for this by adjusting the regression models for participating center in an additional analysis, as the intervals between ESA and/or iron administration and blood sample withdrawal are supposed to be similar within a single treatment center. Since this did not change our results, we conclude that the dosing schedule was not a major confounder in our study. Another potential limitation of our study is the patient selection, based on centers where blood sampling and storage was logistically feasible. This might have introduced a selection bias of which the magnitude and direction cannot be estimated. As selective participation or non-participation must have occurred based on a logistical aspect, which is most probable not related to factors associated with hepcidin or determinants of hepcidin, selection bias seems unlikely.

The strength of our study is the large sample size and the prospective data collection. As far as we know, our study comprises the largest cohort of HD patients in which hepcidin measurements were performed, currently published. The large sample size facilitates multivariable statistics, which is an important method when examining the complex regulation of hepcidin [40]. Moreover, hepcidin measurements have been performed with a validated mass spectrometric technique, enabling specific quantification of the bioactive hepcidin-25.

Conclusions

In this cohort of chronic, stable HD patients, hepcidin-25 levels were independently associated with iron stores (as reflected by ferritin levels), erythropoiesis (reticulocyte count and sTfR), inflammation (hsCRP), GFR, the presence of diabetes and gender. Hepcidin-25 was strongly correlated with its bio-inactive isof orm hepcidin-20, and similar associations with hepcidin-20 were identified. Of note, hepcidin-25 was not associated with the maintenance dose of ESA or iron therapy. Our findings confirm the role of hepcidin as a biomarker of iron stores and erythropoiesis in chronic HD patients and indicate that hepcidin is not a biomarker of ESA resistance in patients on ESA maintenance therapy. Furthermore, it underscores the potential important role of (limited) RKF in HD patients. However, whether low hepcidin levels in HD patients are associated with a favorable outcome in terms of morbidity and mortality is not clear yet. Furthermore, whether hepcidin measurements in HD patients provide additional information concerning anemia management compared to current available markers such as ferritin is questionable.

Supporting Information

File S1 Patient information and informed consent for the CONTRAST study (original in Dutch, translated in English).

Table S1 Baseline characteristics for entire cohort enrolled in CONTRAST (N = 714) and the Hepar din cohort (N = 405).

Acknowledgments

The authors are grateful to patients and nursing staff participating in this project.

Local Investigators:

The Netherlands: Academic Medical Center, Amsterdam – MG Koopman; Dianet Dialysis Centers, Utrecht – M Kooistra and B van Jaarsveld; Gelderse Vallei Hospital, Ede – GW Feith; Haga Hospital, The Hague – M van Buren; Jeroen Bosch Hospital, ’s Hertogenbosch – EK Hoogeveen; Maasstad Hospital, Rotterdam – HJ van de Ven; Martini Hospital, Groningen – TK Kremer Hovinga; Medical Center Alkmaar, Alkmaar – WA Bos; Onze Lieve Vrouwe Gasthuis, Amsterdam – JO Groeneveld; Rijnstate Hospital, Arnhem – LJM Reichert; Slingeland Hospital, Doetinchem – J Huussen; University Medical Center St Radboud, Nijmegen – HW van Hamersvelt; University Medical Center Utrecht, Utrecht – WH Boer; VieCuri Medical Center, Venlo – WH van Kuijk; VU University Medical Center, Amsterdam – MG Vervloet; Zeeuwse-Vlaanderen Hospital, Terneuzen – IMPS J Wauters.

Norway: Haukeland University Hospital, Bergen – I Sekse.

Author Contributions

Conceived and designed the experiments: NCW MPCG MLB MAD CHH JFMW DWS PJB PMW. Performed the experiments: NCW MPCG MLB MAD CHH AHAM MJN ELP ETW DWS. Analyzed the data: NCW MPCG MLB JFMW PMW. Contributed reagents/materials/analysis tools: NCW MPCG CHH AHAM MJN ELP ETW DWS. Wrote the paper: NCW MPCG MLB MAD CHH JFMW DWS PMB PMW.

References


