Effect of treatment frequency on haemodialysis dose: comparison of EKR and stdKt/V

Aarne Vartia

Savonlinna Central Hospital, Keskussairaalantie 6, 57120 Savonlinna, Finland

Correspondence and offprint requests to: Aarne Vartia; E-mail: aarne.vartia@fimnet.fi

Abstract

Background. Haemodialysis outcome cannot be improved by increasing the dialysis session dose above the current standard in conventional schedules. Promising results have been reported from daily dialysis, but the optimal dose has not been established.

Methods. Weekly eKt/V, equivalent renal clearance (EKR) and stdKt/V were compared retrospectively in 588 complete urea kinetic modelling sessions of 35 haemodialysis patients. Equivalent values of EKR and stdKt/V corresponding to the standard and high doses of the HEMO study were defined by computer simulation. The effect of frequency on the dose measures was demonstrated by simulating different schedules.

Results. EKR and stdKt/V take into consideration both frequency and RRF, but appreciate them differently. The values of EKRc (EKR in millilitres per minute, normalized to distribution volume 40 l), stdEKR (EKR in litres per week divided by urea distribution volume in litres) and stdKt/V corresponding to eKt/V 1.20—close to the standard dose in the HEMO study—were 13.2 ml/min/40 l, 3.34/wk and 2.23/wk, respectively. stdKt/V appreciates frequency more than EKR. A spreadsheet was created to compute the dialysis session time to achieve the EKR or stdKt/V target when the basic urea kinetic variables are known.

Conclusions. Haemodialysis efficiency can be increased by increasing frequency. EKR and stdKt/V are more appropriate than weekly eKt/V as measures of dialysis dose in different schedules. With increasing frequency, stdKt/V as the dosing target results in shorter treatment times and higher concentrations than EKR.

Keywords: computer simulation; dialysis dosing; EKR; eKt/V; stdKt/V

Introduction

According to the HEMO study [1], the outcome of haemodialysis (HD) cannot be improved by increasing the session dose (Kt/V) above the current standard of a three times per week schedule. Kt/V is a measure of a single dialysis session. Weekly Kt/V (wKt/V) is the sum of the Kt/Vs of 1-week sessions. It is—in theory—the same whether the patient is dialysed 6 h two times per week or 2 h six times with the same dialysers clearance (Kd). According to numerous reports, the latter schedule yields better outcomes.

In CAPD (continuous ambulatory peritoneal dialysis) patients with total ‘weekly Kt/V’ 2.0 do equally well as patients on HD with wKt/V 3.6. What we call ‘weekly Kt/V’ in CAPD is the fractional clearance (K/V): continuous clearance K divided by distribution volume V relating it to body size. The unit is ‘/wk’. The only problem is estimation of V, which in intermittent HD comes from the urea kinetic model (UKM). Fractional clearance can be used as a measure of renal function, too.

Equilibrated Kt/V (eKt/V) takes the compartment disequilibrium into account and helps in avoiding underdialysis in short high-efficiency treatments and in small patients, but weekly eKt/V (weKt/V)—like wKt/V—ignores the significance of frequency.

Weekly Kt/V and weKt/V have been reported to be higher in short daily HD with equal weekly treatment time and other dialysis parameters [2–4]. The dialysers clearance may decrease during the session due to clotting and accumulation of material on the membrane, so, on average, it may be higher in shorter sessions with equal blood and dialysate flow. On the other hand, wKt/V [5] and weKt/V [6] have also been reported to remain unchanged on switching from three to six times per week treatment with the same weekly treatment time.

In addition to wKt/V and weKt/V, several methods have been proposed for evaluation of the equivalency of renal function and different intermittent and continuous dialysis techniques:

- weekly urea reduction ratio (URR) [5–7]
- weekly solute removal index (SRI) [8–10]
- weekly fractional solute removal (FSR) [11]
- EKR (equivalent renal clearance, Casino and Lopez) [12]
- stdKt/V (Gotch) [13]
- nKt/V (Depner) [14].
Chen et al. [7] observed that weekly $K_t/V$ values of CAPD patients and weekly URls of HD patients were similar to each other. Cheng et al. [10] reported higher weekly URR values for CAPD than for HD patients despite markedly higher $W_t/V$ in HD. Maduell et al. [5] and Williams et al. [6] observed higher weekly URR in short daily than in conventional treatment with the same weekly treatment time and $W_t/V$ or $wK_t/V$.

The optimal dose measure for schedules other than three times weekly has not been established [15]. The European guidelines [16] recommend std$K_t/V$, EKR and SRI. Unfortunately, SRI has conflicting definitions.

The objective of the current retrospective observational analysis is

1. to determine the EKR and std$K_t/V$ values corresponding to the standard and high doses of the HEMO study and
2. to compare EKR and std$K_t/V$ as measures of dialysis dose in symmetric schedules with different frequencies.

**Subjects and methods**

Detailed description of the abbreviations, symbols, definitions and equations is presented in the Appendix.

Data have been gathered by a dialysis information system in the routine care of HD patients. No randomization, control group or study protocol has been used.

Urea kinetic modelling with three blood samples and interdialysis urine collection was done once per month (modelling session). Postdialysis blood samples were taken at the termination of the session with a modified KDOQI slow-blood-flow technique [17]. Postdialysis urea concentrations were converted to equilibrated ones by the Tattersall method [18]. Then all calculations were done using the classic single-pool variable-volume urea kinetic model (spvvUKM) [19,20] with the equilibrated postdialysis values. The urea generation rate ($G$) and distribution volume ($V$) are required in computing the protein equivalent of total nitrogen appearance (nPNA), EKR and std$K_t/V$.

**Dialysis sessions**

The analysis is based on 588 data sets collected between 1 January 2004 and 31 December 2006 from 35 prevalent HD patients having at least one complete urea kinetic modelling session after the first 4 weeks of dialysis. All patients were white Europeans. The modelling sessions are described in Table 1.

**Residual renal function (RRF)**

RRF is expressed as renal urea clearance $Kr$ (ml/min) and renal fractional urea clearance $rFC$ (/wk). The entire interdialysis urine was collected. The calculation of $Kr$ is described in the Appendix. If $Kr$ was below 1 ml/min in three consecutive measurements, $Kr$ and diuresis were stated as zero and urine was not collected in subsequent modelling sessions.

**Dialysis dose**

All variables, including $G$, $Vt$, $Kr$, rFC, nPNA, EKR and std$V$, are based on equilibrated postdialysis concentrations although explicitly noted only on eKt/V.

Dialysis dosing is expressed in four ways:

1. **EKRc**: EKR normalized to distribution volume of 40 l, expressed in ml/min units (Casino and Lopez)
2. **stdEKR**: EKR divided by distribution volume, expressed in /wk units to facilitate comparison to std$K_t/V$
3. **std$K_t/V$ (Gotch)** in /wk units
4. **weekly eKt/V**: the sum of the eKt/Vs of 1-week treatment sessions, in /wk units.

Time-averaged concentration (TAC) and average predialysis concentration (PAC), needed in calculating EKR and std$K_t/V$, cannot be derived from a single modelling session. Treatment parameters were averaged over 4 weeks preceding and including the modelling session. The actual dialyser urea clearance (Kd) of each treatment was calculated from actual blood and dialysate flow (Qb, Qd) and the mass transfer area coefficient (KoA) of the dialyser [21]. KoA is based on several blood side blood water clearance measurements of each dialyser model. Dialysers were used only once.

Treatments were equalized by iterating the spvvUKM concentration equation [19] sequentially over average treatment time and average interval time until plateauing of the predialysis concentration (see the Appendix). This procedure modifies an asymmetric schedule to an evenly distributed one, but has no influence on the patient-specific values.

**Simulations**

The effect of treatment frequency on the measures of dialysis dose was studied by computer simulations. They are based on the classic spvvUKM with the patient-dependent values $G$, $Vt$ and $Kr$ from the modelling session and varying treatment values, keeping weekly ultrafiltration unchanged and assuming that dialysis has no effect on urea generation and renal function.

**Statistical methods**

Microsoft Excel 2002 software was used in calculating minimum and maximum values and standard deviations and in creating the graphs.

**Results**

**Equivalent doses**

Equivalent values corresponding to the standard and high dialysis doses of the HEMO study were determined by simulating a conventional dialysis with a symmetric $3 \times 4$ h/wk schedule and eKt/V 1.20 and 1.60 in the study material (Table 2), respectively. Dialysis intensity was adjusted by dialyser clearance. Numbers in the table are averages of the 588 sessions. The most important parameters are in bold.

The simulated values of EKRc, stdEKR and std$K_t/V$ corresponding to eKt/V 1.20—close to the standard dose in the HEMO study (1.16)—are 13.2 ml/min/40 l, 3.34/wk and

### Table 1. Modelling sessions

<table>
<thead>
<tr>
<th>Number of sessions</th>
<th>Value/average</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sessions with RRF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>32.8</td>
<td></td>
<td>30.0</td>
<td>43.4</td>
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<tr>
<td>%</td>
<td>22.7</td>
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<td>10.0</td>
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<td>Years</td>
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<td>60.0</td>
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<tr>
<td>Height</td>
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<td>10</td>
<td>187</td>
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<tr>
<td>Postdialysis weight</td>
<td>kg</td>
<td>78.7</td>
<td>15.4</td>
<td>43.3</td>
</tr>
<tr>
<td>Total body water</td>
<td>l</td>
<td>1</td>
<td>8.1</td>
<td>24.6</td>
</tr>
<tr>
<td>Height</td>
<td>cm</td>
<td>169</td>
<td>10</td>
<td>187</td>
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<tr>
<td>Postdialysis weight</td>
<td>kg</td>
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<tr>
<td>Total body water</td>
<td>l</td>
<td>1</td>
<td>8.1</td>
<td>24.6</td>
</tr>
<tr>
<td>Kinetic urea distr</td>
<td>volume</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Urea generation</td>
<td>µmol/min</td>
<td>218</td>
<td>73</td>
<td>547</td>
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<tr>
<td>nPNA</td>
<td>g/kg/day</td>
<td>1.01</td>
<td>0.24</td>
<td>2.13</td>
</tr>
<tr>
<td>Diuresis</td>
<td>l/day</td>
<td>0.19</td>
<td>0.35</td>
<td>1.69</td>
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<tr>
<td>Renal urea clearance</td>
<td>ml/min</td>
<td>0.65</td>
<td>1.29</td>
<td>5.10</td>
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<tr>
<td>Renal fractional</td>
<td></td>
<td>0.16</td>
<td>0.27</td>
<td>0.98</td>
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</tbody>
</table>
Effect of treatment frequency on haemodialysis dose

Table 2. Average equivalent measures of HEMO standard and high doses

<table>
<thead>
<tr>
<th>Data</th>
<th>Unit</th>
<th>Actual equalized</th>
<th>HEMO standard 3 × 4 h</th>
<th>HEMO high 3 × 4 h</th>
<th>HEMO high 3 × 5 h</th>
<th>HEMO high 6 × 2.5 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dialysis frequency</td>
<td>/wk</td>
<td>3.12</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>6.00</td>
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<tr>
<td>Dialysis time</td>
<td>min</td>
<td>292</td>
<td>240</td>
<td>240</td>
<td>300</td>
<td>150</td>
</tr>
<tr>
<td>Weekly dialysis time</td>
<td>h</td>
<td>15.2</td>
<td>12.0</td>
<td>12.0</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Predialysis concentration</td>
<td>mmol/l</td>
<td>19.8</td>
<td>23.3</td>
<td>20.3</td>
<td>20.1</td>
<td>15.4</td>
</tr>
<tr>
<td>Equilibrated postdialysis concentration</td>
<td>mmol/l</td>
<td>5.5</td>
<td>8.6</td>
<td>5.3</td>
<td>5.4</td>
<td>7.8</td>
</tr>
<tr>
<td>Time-averaged concentration</td>
<td>mmol/l</td>
<td>12.7</td>
<td>16.1</td>
<td>12.9</td>
<td>12.8</td>
<td>11.6</td>
</tr>
<tr>
<td>Dialyser clearance</td>
<td>ml/min</td>
<td>213</td>
<td>200</td>
<td>200</td>
<td>213</td>
<td>213</td>
</tr>
<tr>
<td>Ultrafiltration volume</td>
<td>l</td>
<td>2.73</td>
<td>2.84</td>
<td>2.84</td>
<td>2.84</td>
<td>1.42</td>
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<tr>
<td>Equilibrated Kt/V</td>
<td></td>
<td>1.59</td>
<td><strong>1.20</strong></td>
<td></td>
<td></td>
<td><strong>1.60</strong></td>
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<tr>
<td>Weekly equilibrated Kt/V</td>
<td>/wk</td>
<td>4.93</td>
<td>3.60</td>
<td>4.80</td>
<td>4.80</td>
<td>4.80</td>
</tr>
<tr>
<td>EKRc (Casino and Lopez)</td>
<td>ml/min/40 l</td>
<td>16.9</td>
<td><strong>13.2</strong></td>
<td></td>
<td></td>
<td><strong>16.4</strong></td>
</tr>
<tr>
<td>stdEKR</td>
<td>/wk</td>
<td>4.26</td>
<td><strong>3.34</strong></td>
<td></td>
<td></td>
<td><strong>4.14</strong></td>
</tr>
<tr>
<td>stdKt/V (Gotch)</td>
<td>/wk</td>
<td>2.63</td>
<td><strong>2.23</strong></td>
<td></td>
<td></td>
<td><strong>2.54</strong></td>
</tr>
</tbody>
</table>

2.23/wk, respectively. Weekly eKt/V and stdEK are remarkably higher than stdKt/V, far above the range achieved in CAPD. The values of EKRc, stdEK and stdKt/V corresponding to eKt/V 1.60—close to the high dose in the HEMO study (1.53)—are 16.4 ml/min/40 l, 4.14/wk and 2.54/wk, respectively.

It may be difficult to achieve eKt/V 1.60 in 4 h. The last two columns of Table 2 represent the HEMO high dose equivalent values in symmetric 3 × 5 h/wk and 6 × 2.5 h/wk schedules, respectively. Uraemic toxicity is probably related to concentrations. Predialysis and TACs are lower with higher frequency, although generation and elimination rates, treatment time and dialysis fluid consumption are equal. This may be interpreted as better efficiency and is reflected in higher EKR and stdKt/V, but not in weKt/V.

Effect of frequency

The simulations are based on weekly eKt/V, stdEK and stdKt/V as measures of dialysis dose.

Figure 1 describes the effect of frequency on different measures of dialysis dose in a patient with average characteristics of the study material (Table 1). Frequency affects stdKt/V more than stdEK. Weekly eKt/V is not dependent on frequency.

Figures 2–4 represent the patient dialysed with the standard-equivalent doses defined in Table 2.

Figure 2 describes the effect of frequency on the weekly treatment time required to achieve the standard-equivalent doses with constant Kd. Much more time is needed to achieve the stdKt/V target in a two times per week schedule than in three times per week. The effect of frequency is less steep with stdEK as the target dose measure.

With higher frequency, using stdKt/V as the target results in higher concentrations (C0 and TAC) than stdEK (Figures 3 and 4).

The curves in Figures 1–4 are based on a simulated patient with G = 218 µmol/min, V = 40.0 l, Kr = 0.65 ml/min (Table 1) and UF = 8.5 l/wk (Table 2). With the spreadsheet DoseOpt.xls in http://www.verkkomunuainen.net/optimize.html, the dialysis prescription can be planned individually.

Discussion

The current analysis is based on the UKM. One of the parameters in this model is renal urea clearance, which is lower than the glomerular filtration rate.

HD urea kinetics can be described rather accurately by a two-pool model that requires several blood samples or a dialysate urea monitor. Using single-pool UKM with dialyser clearance and equilibrated postdialysis concentration as input parameters is a practical shortcut, although incorrect in theory. It involves mixing of single- and double-pool models and overestimates Vt to compensate the difference between dialyser clearance and whole body patient clearance to give a ‘correct’ eKt/V. This concept was used as the
reference in a HEMO pilot study in choosing the method to measure the delivered dialysis dose [22]. Inaccuracy of the single-pool model affects the equalization procedure and simulations in the current study.

The current material differs in several aspects (age, weight, race, sex distribution, anthropometric total body water, maximum rFC) from the HEMO study. In a different population, the values of EKR and stdKt/V corresponding to eKt/V 1.2 and 1.6 may be different.

Weekly measures of dialysis dose are required in comparing different schedules, but as seen from Table 2 and the figures and argued in the literature [13,14], weekly eKt/V underestimates the therapeutic significance of frequency.

In CAPD, stdKt/V and stdEKR are equal to the fractional clearance ("weekly Kt/V"). In standard HEMO-equivalent dialysis (Table 2), the average stdKt/V (2.23 /wk) is comparable to the stdKt/V of CAPD patients. Possibly the greater unphysiology (fluctuation of volume and concentrations, compartment disequilibrium) and different sieving profiles of the membrane have to be compensated by a slightly greater dose in HD to achieve equal outcome.

According to the European guidelines [16], in anuric patients, treated by three times per week dialysis, the prescribed target eKt/V should be at least 1.2, and for patients with renal function or those with dialysis schedules other than three times per week, weekly dialysis dose should be at least equivalent to an SRI of 2. In a symmetric schedule, SRI—as defined in the guidelines—is equal to stdKt/V. In the current material, the SRI or stdKt/V value corresponding to a delivered eKt/V of 1.2 is considerably higher. The difference corresponds to 42 min of session time (198 versus 240 min) in a symmetric three times per week schedule with a Kd of 200 ml/min. SRI 2.00/wk corresponds to eKt/V 0.99. With significant RRF, a lower value of SRI or stdKt/V may be acceptable, because it, based on the UKM, underestimates renal function.

Future investigation is needed to elucidate whether increasing the dialysis dose above the equivalents of the HEMO standard dose by increasing the frequency is of any prognostic benefit and whether increased dose or decreased unphysiology [23] is more important in frequent dialysis.

stdKt/V appreciates frequency more than EKR. If diminished unphysiology is the most essential advantage of frequent dialysis, then dosing is best guided by stdKt/V resulting in shorter weekly treatment time with increasing frequency, but if dose is important, then EKR is more suitable resulting in lower concentrations.

Conflict of interest statement. None declared.
Appendix

Abbreviations and symbols

UKM = urea kinetic model
spvvUKM = single-pool variable volume UKM
RRF = residual renal function
HD = haemodialysis
CAPD = continuous ambulatory peritoneal dialysis
Qb = blood flow
Qd = dialysate flow
t = observation period duration
td = dialysis session duration
ti = dialysis interval duration
fr = dialysis session frequency
G = generation rate
E = removal rate
K = clearance
Kd = diffusive blood water dialyser clearance
KoA = mass transfer area coefficient of the dialyser
Kr = renal clearance
rFC = renal fractional clearance
C = concentration
C1 = concentration at the beginning of the observation period
C2 = concentration at the end of the observation period
C0 = concentration at the beginning of a dialysis session
Ct = equilibrated postdialysis concentration
C02 = concentration at the beginning of the next dialysis session
TAC = time-averaged concentration, computed using equilibrated postdialysis concentration
PAC = average predialysis concentration, average C0
Cu = urine concentration
V = distribution volume
V1 = distribution volume at the beginning of the observation period
V0 = distribution volume at the beginning of a dialysis session
Vt = distribution volume at the end of a dialysis session
V02 = distribution volume at the beginning of the next dialysis session
Va = average distribution volume
Vu = interdialysis urine volume
VG = fluid accumulation during the observation period
VGd = fluid accumulation during a dialysis session, usually negative
VGi = fluid accumulation between dialysis sessions
WGi = weight gain between dialysis sessions
UF = ultrafiltration volume (positive, if fluid is removed)
URR = urea reduction ratio
SRI = solute removal index
FSR = fractional solute removal
tFSRR = average total fractional solute removal rate (renal + dialysis)
wtFSR = weekly total fractional solute removal (renal + dialysis)
RUR = renal urea removal, amount of urea in interdialysis urine
DUR = amount of urea removed in a dialysis session
Kt/V = dialysis session dose, single pool
eKt/V = equilibrated dialysis session dose
wKt/V = weekly Kt/V
weKt/V = weekly eKt/V
EKR = equivalent renal urea clearance, a measure of dialysis dosing defined by Casino and Lopez [12]
EKRc = EKR normalized to a urea distribution volume of 40 l
stdKt/V = a measure of dialysis dosing defined by Gotch [13]
stdEKR = EKR divided by V; comparable to stdKt/V
NBW = normal body weight
PNA = protein equivalent of total nitrogen appearance
nPNA = normalized PNA

Definitions and calculations

VGi = WGi (in conjunction with the actual modelling session) (A.1)

VGi = UF (in the equalized schedule) (A.2)

V0 = Vt + UF (A.3)

V02 = Vt + VGi (A.4)

Va = (V0 + Vt)/2 (A.6)

RUR = Vu*Cu (A.7)

DUR = V0°C0 – Vt*Ct + td*G (A.8)

G = (V02*C02 – Vt*Ct + RUR)/ti (A.9)

tFC = Kr/Vt (A.10)

Kt/V = Kd*td/Vt (A.11)

wKt/V = fr*Kt/V (A.12)

weKt/V = fr*eKt/V (A.13)

nKt/V = 0.92*fr*(1 – exp(−1.1*Kt/V)) (A.14)

NBW = Vt/0.58 (assuming 1 litre weighs 1 kg) (A.15)

nPNA = PNA/NBW. (A.16)

The Sargent modification [24] of the original Borah equation [25] was used in calculating PNA.
EKR (equivalent renal urea clearance) and stdKt/V are based on the definition of clearance:

K = E/C. (A.17)

In steady state E = G, so

K = G/C. (A.18)

In EKR, the term C of equation (A.18) is the time-averaged concentration (TAC), in stdKt/V, the average predialysis concentration (PAC). According to the definition, stdKt/V
is normalized by dividing the value of equation (A.18) by the distribution volume $V$. Dividing $EKR$ by $V$ yields a variable called here as stdEKR (eqKRt/V in [26]):

$$\text{stdEKR} = G/TAC/Va \quad \text{(A.19)}$$

$$\text{stdKt/V} = G/PAC/V0. \quad \text{(A.20)}$$

The unit of stdEKR and stdKt/V is /wk. To ensure conformity with wtFSR, predialysis volume (V0) is used in stdKt/V, average volume (Va) in stdEKR.

EKRc is calculated by multiplying a 'normal' distribution volume 40 l and divided by the number of minutes in a week (10 080) [12]:

$$\text{EKRc} = 3.97^{*}\text{stdEKR}. \quad \text{(A.21)}$$

The unit of EKRc is ml/min/40 l.

Weekly total fractional solute removal (wtFSR) is the amount of urea removed by dialysis and the kidneys during 1 week divided by the average predialysis amount of urea in the body. More generally

$$\text{tFSRR} = E/(PAC*V0). \quad \text{(A.22)}$$

As seen from equations (A.20) and (A.22), tFSRR = stdKt/V, if $E = G$, wtFSR is tFSRR with week as the time unit like in stdKt/V. Only stdKt/V is used in the Results section.

Kr is computed by searching for the value that yields $C0_2$ from Ct. Calculations of $G$, $V$ and Kr are included in the same iteration loop:

- $Vt = \text{ASV}$ (arbitrary starting value)
- repeat
  - $Vp = Vt$ (previous Vt)
  - $G = ((Vt + VGi)^*C0_2 - Vt^*Ct + RUR)/ti$ (different from classic UKM)
  - $Kr = fK(Ct, C0_2, Vt, VGi, ti, G)$ (binary search (declared below))
  - $Vt = fVt(C0, Ct, -UF, td, Kd, Kr, G)$ (spvvUKM Vt equation)
- until Abs(Vt − Vp)/Vt < 0.00001

The parameters of function $fVt()$ are C1, C2, VG, t, Kd, Kr and G. It returns Vt.

- function $fK(C1, C2, V1, VG, t, G)$ (computation of clearance by binary search)
  - $K1 = 0$ (lowest possible value of clearance K)
  - $K2 = MAX$ (highest possible value of clearance K)
- repeat
  - $K = (K1 + K2)/2$
  - $Cc = fCt(C1, V1, VG, t, K, G)$ (spvvUKM concentration equation)
- if $Cc > C2$ then
  - $Cc = \text{calculated concentration}$
  - $K1 = K$
- else
  - $K2 = K$
- end if
- until Abs(Cc − C2)/C2 < 0.00001
- $fK = K$.

Equalizing the schedule to a symmetric one

In column 'Actual equalized' of Table 2, dialysis frequency, dialysis time, weekly dialysis time, dialyser clearance, ultrafiltration volume, equilibrated Kr/V and weekly equilibrated Kr/V are averages of the 4-week averages associated with each modelling session.

Treatments are equalized by iterating the classic spvvUKM concentration equation sequentially over the average treatment time and average interval time until plateauing of $C0$, using Kr, G and Vt from the modelling session and average Kd and average UF:

$$C0 = \text{ASV} \quad \text{‘arbitrary starting value}$$

Repeat
$$Cp = C0 \quad \text{‘previous C0}$$
$$Ct = fCt(C0, Vt+AvgUF, -AvgUF, Avgtd, AvgKd, Kr, G) \quad \text{'spvvUKM concentration equation, dialysis}$$
$$C0 = fCt(Ct, Vt, AvgUF, Avgti, 0, Kr, G) \quad \text{'spvvUKM concentration equation, interval}$$

Until Abs(C0 − Cp)/C0 < 0.00001

The equalization procedure modifies C0 and Ct and facilitates calculations of TAC, PAC, EKR, stdKt/V and wtFSR. PAC is C0 computed by equalizing. TAC is the cycle area_under_the_time/concentration_curve divided by the cycle duration, calculated from the equalized values according to Casino and Lopez [12]. RUR is calculated by multiplying the equalized interdialysis area_under_the_time/concentration_curve (used in TAC calculation) by Kr. In a symmetric schedule, the FSR concept enables assessment of the renal and dialysis components of urea elimination separately without dialysate collection.

References

The impact of dialysis modality on skin hyperpigmentation in haemodialysis patients

Sung Jin Moon*, Dong Ki Kim*, Jae Hyun Chang, Chan Ho Kim, Hyun Wook Kim, Sun Young Park, Seung Hyeok Han, Jung Eun Lee, Tae-Hyun Yoo, Dae Suk Han and Shin-Wook Kang

Department of Internal Medicine, College of Medicine, Brain Korea 21 for Medical Science, Yonsei University, Seoul, Korea

Correspondence and offprint requests to: Shin-Wook Kang; E-mail: kswkidney@yumc.yonsei.ac.kr

*Both the authors contributed equally to this work.

Abstract

Background. Skin hyperpigmentation in end-stage renal disease (ESRD) patients has been attributed to the accumulation of middle-molecular-weight (MMW) substances. Although an MMW mechanism suggests that hyperpigmentation may be improved by high-flux haemodialysis (HF-HD) and haemodiafiltration (HDF), this possibility has not been explored. In the present study, we investigated the impact of different dialysis modalities on skin colour in HD patients.

Methods. Eighty-two ESRD patients on HD were divided into low-flux HD (LF-HD), HF-HD and HDF groups. The melanin index (MI) and erythema index (EI) of the abdomen and the flexor side of the forearm (non-sun-exposed areas) and the forehead (sun-exposed area) were determined by using a narrow-band reflectance spectrophotometer at baseline and after 12 months.

Results. Even though absolute values of baseline and follow-up MI and EI of the three sites were comparable among the three groups, forehead MI and EI were significantly decreased after 12 months in the HDF group (P < 0.05). In addition, the change in forehead MI was significantly greater in the HDF than in the LF-HD group (P < 0.05). Moreover, β₂-microglobulin reduction rates were negatively correlated with both changes in forehead MI (P < 0.01) and EI (P < 0.05).

Conclusions. Skin colour of sun-exposed areas was significantly decreased in ESRD patients receiving HDF therapy, suggesting that enhanced removal of MMW substances by convection may prevent or reduce hyperpigmentation in HD patients.

Keywords: β₂-microglobulin; haemodiafiltration; hyperpigmentation; low-flux haemodialysis; spectrophotometer