Effects of body core temperature reduction on haemodynamic stability and haemodialysis efficacy at constant ultrafiltration

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Introduction

Intradialytic body temperature changes are governed by the thermal energy balance and heat capacity of the body. Resting energy expenditure is dissipated to the environment by evaporation, conduction and radiation. Homeostatic mechanisms maintain body temperature to an individual set-point by changing the radiative heat loss through vasoconstriction and vasodilatation.

During haemodialysis, the extracorporeal circuit has a great effect on intradialytic thermal energy balance. The dialyser is a nearly perfect heat exchanger, whereby blood leaves the dialyser at thermal equilibrium with dialysate. The energy balance in the dialyser is a function of the difference between arterial blood temperature and dialysate temperature as influenced by extracorporeal blood flow and the specific heat and density of blood. Additional effects on intradialytic thermal energy balance come from energy loss in the venous blood line which is dependent on blood–environment temperature differences. Recently a blood temperature monitor (Fresenius AG, Bad Homburg, Germany) has become available that allows continuous monitoring of thermal energy balance and feedback control of body temperature [1]. This is a non-invasive device by which blood temperature is measured in the arterial and venous blood line. The measured arterial and venous temperatures are corrected for temperature reduction between the sensor heads and the dialysis access. From the differences between these temperatures, blood flow and heat capacity of blood, thermal energy balance in the patient is calculated as

\[ Q_b(T_v - T_A) \rho c_p \]

where \( c \) = specific heat capacity of blood, \( \rho \) = blood density, \( T_A \) = arterial line temperature, and \( T_v \) = venous line temperature (°C). In the absence of recirculation, arterial blood represents core temperature. In order to monitor body temperature when recirculation is present, the device is capable of measuring recirculation [2]. Thus a correction can be made for the temperature effect of venous blood mixing with arterial blood proximal to the arterial sensor head. As a result, the blood temperature monitor permits accurate measurement and, via feedback changes in dialysate temperature, control of core temperature.

The beneficial role of blood cooling in promoting haemodynamic stability on haemodialysis has previously been described [3,4]. However, blood cooling has potentially adverse effects on solute disequilibrium [5,6]. Multicompartment models have been developed to explain intradialytic disequilibrium and post-haemodialysis urea rebound. The simplest arrangement is a central (intracellular) and peripheral (interstitial and blood) compartment connected in series with a mass transfer coefficient describing the rate of solute diffusion between compartments. Following dialysis, equilibrium is re-established and the extracellular and intracellular concentrations of urea exponentially approach an equilibrium value. An alternative arrangement is based on physiological data of regional tissue perfusion. In this model, compartments are arranged in parallel with low flow-to-tissue volume (skin and muscle) and high flow-to-tissue volume (heart, brain, lungs) regions. Changes in regional blood flow in low flow areas during haemodialysis can be used to explain intradialytic disequilibrium [7]. Following dialysis, as the circulation returns to normal, urea from the low flow compartments mixes with urea from the high flow compartments and contributes to rebound. High dialyser clearance to body water ratios, found in high efficiency treatments, enhance compartment disequilibrium [8–11]. Blood cooling, could, in theory, further enhance compartmental disequilibrium by producing a thermal-induced change in regional blood flow [12]. This would be manifested by an increase in post-haemodialysis rebound and a concomitant decrease in dialysis efficacy. Warming of an extremity has decreased post-haemodialysis urea rebound from the limb, implying temperature-dependent changes in compartment disequilibrium [13]. However, in preliminary reports, we and others have not demonstrated significant changes in post-haemodialysis urea rebound or
urea kinetic analysis following blood temperature cooling [14,15].

This preliminary study compares the effects of changes in core temperature on blood pressure and post-haemodialysis urea rebound under conditions of high clearance to body water ratios, in which changes in ultrafiltration rate and blood volume are quite similar in experimental groups.

Subjects and methods

Studies were performed in patients receiving high efficiency dialysis using bicarbonate dialysate with a sodium concentration of 142 MEQ/l, F80 dialysers, a prescribed extracorporeal blood flow rate of >400 ml/min, and a dialysate flow rate of 800 ml/min. Fluid removal was maintained constant throughout each dialysis treatment utilizing a volumetric fluid removal system (2008E, Fresenius USA). Each patient participated in both arms of the study in which dialysate temperature was maintained at 37°C (standard, n=9) or reduced utilizing the blood temperature monitor to produce a fall in core temperature =0.2°C (cooled, n=9).

Mean arterial pressure was measured with an automated device and cardiac index from an on-line bioimpedance method. Systemic vascular resistance index was calculated. Changes in blood volume were determined by on-line measurement of hematocrit (In-line Diagnostics) [16]. Thermal balance was determined with the blood temperature monitor. BUN measurement for kinetic analysis were determined pre- (Co), at the immediate end of dialysis (Ct) and at 30 minutes (C+30) post-treatment. Blood urea nitrogen was measured in triplicate by a standard urease method. Standard urea kinetic modelling formulae were utilized for determination of an index of the fractional clearance of urea (Kt/V) [17] except that the equilibrated blood urea nitrogen (BUN) (Cc) was used to arrive at the equilibrated Kt/V(eqKt/V). Cc was determined by multiplying C+30 by 1.039 to correct for continued equilibration and generation [18]. Urea rebound was calculated as follows:

\[ (C_{c} - C_{t})/C_{t} \]

Procedures and protocols were approved by Beth Israel Medical Center Institutional Review Board. Informed consent was obtained from all participants. Standard statistical methods were used.

Results

Blood flow rate, time on treatment and dialytic weight loss were not different between groups and averaged 418 ml/min, 174 min and 2.9 kg, respectively. Dialysate clearance to patient volume ratios (Kt/V) averaged 6.5 ml/min/l. Mean core temperature was significantly decreased with cooling when compared to standard treatment (mean Δ between groups= 0.48°C). Dialysate cooling also resulted in significantly more negative thermal balance than with standard therapy (mean Δ between groups= 204 kJ). Core temperature cooling was associated with a significantly greater change in mean arterial pressure (mean Δ between groups= 9 mmHg), and a lower maximum fall in mean arterial pressure (mean Δ between groups = 17 mmHg).

The mean blood pressure increased in six of nine studies with cooled dialysate and one of nine with standard therapy. The mean change in systemic peripheral vascular resistance index was 483 dyn.s/cm²/m² greater with dialysate cooling than with standard dialysate temperature. In five of nine studies with dialysate cooling and one of nine with standard therapy, mean systemic peripheral vascular resistance increased by more than 10%. There was no significant change in cardiac index in either group during dialysis. Changes in blood volume (~13%) were comparable between groups.

Urea concentration pre-, post- and 30 min post-haemodialysis (Figure 1), urea rebound (44%) and equilibrated Kt/V (1.36) were not significantly different between groups.

Discussion

Haemodynamic stability

During haemodialysis, cooling of dialysate resulted in improved haemodynamic stability (as defined by maintenance of mean arterial pressure) at the same ultrafiltration rate, compared with standard therapy. It was noteworthy that in 67% of the studies blood pressure actually increased with cooling. Because the reduction in intravascular volume was also the same as with standard treatment, differences in vascular refilling cannot explain the haemodynamic findings. Peripheral vascular resistance increased substantially in 56% of patients treated with cooled dialysate and in only 11% treated with standard therapy. Further studies are needed to determine the mechanism of improved haemodynamic stability with dialysate cooling and to differentiate the degree of vasoconstriction occurring as the result of ultrafiltration from that observed with cooling alone.
Effects of body temperature reduction on haemodialysis efficacy

Effect on urea kinetics

During haemodialysis, solute is removed from multiple compartments. Differences in slow flow compartment perfusion and recovery in response to haemodialysis have been hypothesized to contribute to differences between post-haemodialysis urea rebound between different subjects. Thus reduction of flow to muscle, for example, could result in sequestration of solute and consequently less effective haemodialysis. This would be manifested by an increase in post-haemodialysis rebound when the re-establishment of regional blood flow post-haemodialysis results in equilibration with systemic blood. However, in the current study, there were no differences between the two groups in post-haemodialysis urea rebound or equilibrated $K_t/V$, the standard by which haemodialysis efficacy can be measured.

Thus when core temperature cooling is used to stabilize blood pressure with rapid haemodialysis, additional adjustments in the prescription beyond that which are necessary for compartment disequilibrium accompanying rapid haemodialysis [19] do not appear necessary. Controlled core temperature cooling helps to maintain blood pressure without compromising the efficacy of haemodialysis at least with the parameters tested. Whether greater cooling is required to achieve haemodynamic stability in some unresponsive patients, and whether this will reduce the efficacy of dialysis, will require further work.

Implications of blood temperature monitoring in nephrology

Standard dialysate temperature settings of 37°C do not take into account the variable and usually lower core temperature of most patients with uraemia. Under these conditions thermal energy is applied to the patient during dialysis, invoking thermoregulatory adaptations that redistribute central blood volume to the peripheral circulation, thereby promoting vasodilatation and hypotension. These effects would be expected to occur more commonly in rapid, high efficiency dialysis when interdialytic volume gains are removed over short periods of time. Arbitrarily choosing a lower dialysate temperature to promote haemodynamic stability produces imprecise thermal balance effects because of the substantial variation of core temperatures (as much as 2°C) in different patients. Thus the use of a closed control loop to modify dialysate temperature to produce negative extracorporeal heat balance throughout treatment, which is linked to the patient's own core temperature measurements, makes theoretical and practical sense. Attention to thermal balance may have particular importance in patients with poor cardiac function, and in whom blood pressure stability may be critically dependent on increases in peripheral vascular resistance during haemodialysis. Since hypotension is a common problem in dialysis, especially with rapid therapies, this approach is a useful application. Possibly only patients with initial low temperatures benefit from cooled dialysate [20].

In some patients, marked increases in intradialytic and post-dialytic blood pressure occur despite ultrafiltration. To the extent that these changes are undesirable and are caused by increases in peripheral vascular resistance, the increase in pressure might be ameliorated by a thermal balance profile with a smaller effect on peripheral vasoconstriction.

An additional application of blood temperature monitoring is the measurement of recirculation by briefly reducing the dialysate temperature and observing the effects on the arterial line temperature. The measurement includes access and cardiopulmonary recirculation. At present little can be done about the measurement of cardiopulmonary recirculation. However, increases in access recirculation herald access thrombosis and reduce dialysis efficacy. Blood temperature monitoring permits the possibility of prospectively diagnosing some dialysis access problems, thereby preventing complicated treatment dilemmas when accesses unexpectedly fail. In addition, blood temperature monitoring can detect recirculation caused by faulty needle placement which is readily correctable. With a well-functioning access with minimal recirculation, dialysis efficacy is then determined by the more controllable technical aspects of treatment.

References


