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TECHNIQUE

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A technique for the monitoring of blood flow during continuous haemofiltration

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Abstract *Objective:* To establish a technique for the monitoring and graphic display of blood flow during continuous renal replacement therapy (CRRT). *Design and setting:* Technique assessment study in a tertiary intensive care unit.
Patients: Six ICU patients receiving CRRT. *Interventions:* A technique was devised to monitor and graphically display blood flow during CRRT. This technique used a mini-ultrasound Doppler probe attached to the blood tubing with link to a lap top computer for quantitative graphic display. Blood flow was measured and displayed during routine treatment using this method in six patients. *Measurements and results:* Blood flow wave data were monitored and successfully displayed as a real-time wave form and analysed using Windaq data analysis software. This initial analysis over a 6-h period revealed the following facts: (a) blood flow was not the same as set by the machine roller pump on nine occasions, (b) blood flow reductions defined as a drop in the 'diastolic' were 20% (seven) and 30% (two) less than set flow, (c) flow reductions frequently failed to trigger machine alarms, and (d) the blood flow wave displayed had unique characteristics. Complete flow monitoring was then undertaken for the functional life of one haemofilter over 24.5 h. There were 27 blood flow reductions, and blood flow was less than set for a total of 463.9 min or 31.5% of operating time.
Conclusions: Blood flow during CRRT can be monitored by an ultrasound Doppler probe and displayed graphically. Preliminary data using this technique suggest potentially serious and undetected problems with blood flow during routine CRRT.

Keywords Haemofiltration · Continuous renal replacement therapy · Blood flow Doppler ultrasound · Intensive care unit · Peristaltic pumps · Haemodialysis · Critical illness · Acute renal failure

Introduction

Reliable blood flow during continuous renal replacement therapy (CRRT) is essential for effective solute clearance and for the prevention of premature filter clotting. In veno-venous CRRT such flow is controlled by a peristaltic roller pump [1]. It is widely held that blood flow as set by CRRT machine pumps is correct with no or minimal fluctuation. Clinical experience with CRRT, however, raises some concern that blood flow is not always maintained as set. No technique exists to monitor and display blood flow as a monitored wave during CRRT. We hypothesized that real blood flow could be monitored by Doppler technology, and that wave analysis could be achieved by computer screen display. Thus we sought to develop this technique for use in the ICU.

Materials and methods

Consent

Approval for the study was obtained from the Medical Centre Ethics Committee, and signed consent was gained for each patient studied.

Instrumentation: CRRT set up and system

CRRT was performed utilizing a BMM 10–1 blood monitor (CGH Medical, Lund, Sweden) incorporating a convective solute clearance circuit with a Hospal 1.3 m2 AN69S membrane (Hospal, Lyon, France). The blood pump roller was calibrated to the correct occlusive gap according to the manufacturer's specifications. Fluid replacement was administered through the pre-roller pump access port. Effluent was removed from the top membrane port. Both effluent and replacement fluids were controlled by Gemini IV pumps (IMED, San Diego, Calif., USA). Anticoagulation was administered in the post-roller pump access to the circuit and controlled by a Gemini IV pump (IMED).

An ultrasound Doppler flow probe was used to measure actual blood flow. This probe is a four crystal beam miniature device which clamps around the blood tubing illuminating the blood flow between the opposing walls of the tubing. A microchip processor receiving the Doppler signals calculates transit time for blood passing through the probe head and displays a measure of flow. The study probe was made and factory calibrated for the tubing used. The probe provides 200 samples per second to the software as millivoltage to generate a flow wave. This high frequency response ensures that instantaneous flow is accurate. The millivolt signal can then be cross calibrated or zeroed against a known flow rate or no flow for display in millilitres/minute.

This system was cross-calibrated for accuracy against a radiography radio-opaque contrast injection device (Biotel PJ3 Mk2, Contrast Injector, Biotel, Sydney, Australia). Saline solution was injected by this device into CRRT tubing at various rates, and the flow measured. In addition, a static flow test was performed using normal saline draining via CRRT tubing from a bag at a flow rate of 100 ml/min. The probe readings were accurate to ±1 ml/min during both these tests.

Doppler flow measurement unit and computer interface

The flow probe and bedside monitor was a Neomedix systems, Transonic HT 109 device (Neomedix, Ithaca, N.Y., USA). Data were acquired from this monitor by a lap top computer via an RS232 port. A Windows based data acquisition and playback software program (WinDaq Software, Transonic Systems) converted these data to a wave form for recording and playback. The waveform recorded and played back on the computer screen view is displayed in Fig. 1.

Procedure

A flow rate of 200 ml/min was the set flow during CRRT. The ultrasonic flow probe was connected to the CRRT blood line and positioned between the roller pump and the filter. The probe cable was then plugged into the bedside flow monitor and ultrasound signal quality verified.

Results

Computer analysis of flow reductions

With the flow set at 200 ml/min, the waveform demonstrated a peristaltic flow pattern with a peak (systolic) flow of 194 ml/min and a trough (diastolic) flow of 83 ml/min (Fig. 1). The computer screen grid was used

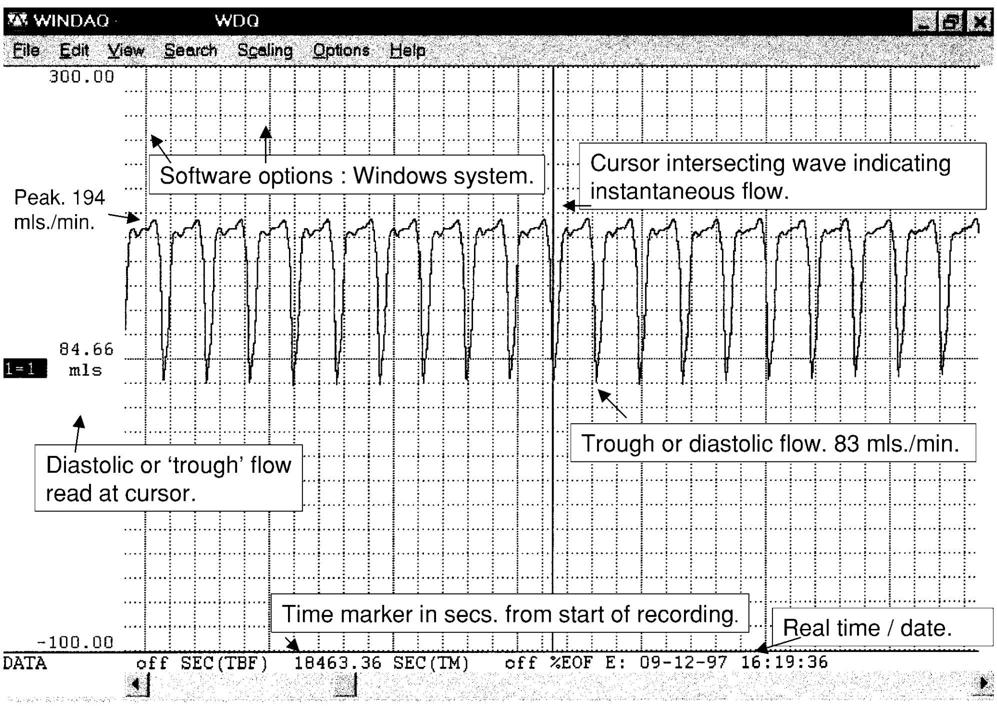

Fig. 1 Wave recorded from Doppler probe and displayed on computer screen. Screen functions and blood flow wave peak and trough indicated. Horizontal grid lines used to identify flow reduction occurring and recorded as percentage reduction from the normal diastolic flow of 84 ml/min

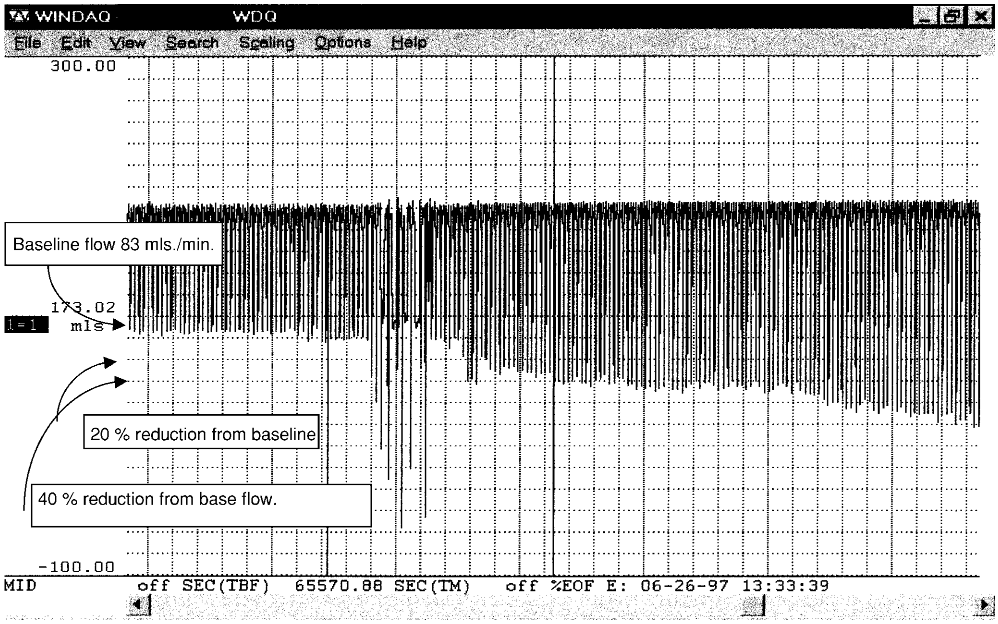

Fig. 2 Compressed waves indicating a 20% and 40% reduction grid line. Flow reduction increases over time to the 80% level of severity. Baseline flow grid is marked at the grid line for normal diastolic flow of 83 ml/min when the machine set flow is 200 ml/min

to mark the line of normal diastolic flow (Fig. 1). When the trough component of the wave fell below this grid line, a flow reduction was said to occur and expressed as a percentage change from normal diastolic flow. One grid line section represented a reduction of 16.6 ml/min (20% reduction, actual flow of 67.4 ml/min). By this method flow reductions were easily identified during high-speed scrolling (wave compression) of data on the computer during playback and analysis (Fig. 2).

Blood flow waveform

Monitoring was initially performed in six patients for limited periods of time (2–6 h) to establish feasibility and the graphic characteristics of a 'normal blood flow wave'. This monitoring revealed a graphic peristaltic blood flow pattern with a peak or maximum flow (systolic), preceded by a period of flow acceleration, and a trough or minimum flow (diastolic), preceded by flow deceleration. The vertical distance between peak and trough is the wave amplitude. Each waveform appears at a rate (frequency) consistent with the pump speed setting. At lower pump settings the frequency and amplitude of the wave decrease. Both the frequency and amplitude of the wave therefore determine real blood flow. At a pump setting of 200 ml/min real peak blood flow was 194 ml/min, and real trough blood flow was 83 ml/min. Thus the blood pump setting of 200 ml/min is misleading and does not represent "mean" blood flow.

Blood flow reductions

Our technique displayed flow reductions during operation in both components of the flow wave.

Systolic flow reductions

A systolic flow reduction occurred when the peak flow was not achieved as set by the machine. Such reductions occurred frequently because the pump generated a peak flow slightly under the set value. For a pump speed of 200 ml/min the measured peak flow was generally about 194 ml/min.

Diastolic flow reductions

These reductions were defined by a decrease in the minimum flow rate below 83 ml/min. These were observed in all patients and caused a corresponding reduction in mean blood flow. As flow reduction was associated with the diastolic flow specifically, this was the parameter we used for analysis and report here.

Blood flow was then monitored continuously in one patient over the entire life of the haemofilter (24.5 h). Vascular access was by a dual lumen catheter (Quinton Mahukhar, 11.5 F, Seattle, Wash., USA) in the right-sided subclavian position. Diastolic blood flow reductions occurred 27 times. There were 18 flow reductions at 20%, three at 40%, five at 60% and one at the 80% levels of severity. These events were identified from the compressed wave view as indicated in Fig. 2. The duration of these events was 436.6, 7.25, 17.28 and 2.77 min, respectively. Therefore diastolic blood flow was less than normal for a total of 463.9 min or 31.5% of operating time.

Discussion

We describe a novel technique to accurately monitor and graphically display blood flow during CRRT. During veno-venous CRRT the roller pump rotates at a rate set by the operator and displayed as millilitres/minute on the pump module [2]. Unfortunately, these pumps may not always deliver the set amount. Depner et al. [3] have suggested that any resistance to blood flow before or after the pump can reduce flow in the circuit by up to 50% of desired (set) value. The findings of this study support this statement.

Why graphic monitoring of blood flow may be important

Graphic waveform display and analysis is an important advance in the detection of circuit malfunction because its alternative, digital analysis, is grossly insensitive. Digital analysis in fact averages several peak signals in order to give a stable average digital value at peak or maximum. This approach misses flow reductions between peaks. Real time waveform display, however, does not. It demonstrates the blood flow past the Doppler probe creates a peak or rapid rise in real flow as the roller cam completes its forward stroke. This peak is followed by a trough or diastolic point. It is the amplitude or vertical distance from the peak of the wave to the trough, which represents a blood flow reduction due to inadequate refilling of the tubing during the “off” period of the cam. When this occurs, the very same blood may simply pass backwards through the pump tubing, refilling it retrogradely until the cam of the roller begins its next forward compression stroke. This dysfunctional cycle is undetectable without graphic display and is similar to the effect of a leaking heart valve with a reduction in real output. The drop in flow between pump strokes constitutes such reduced output, which was recorded as percentage reduction in diastolic flow. Waveform display and interpretation is therefore necessary for the accurate diagnosis of reduced blood flow. It mirrors the significance and usefulness of flow volume measurements seen in modern ventilators. Many CRRT circuits may clot not because of inadequate anticoagulation but because of inadequate flow. Our method makes the diagnosis of inadequate flow possible. Correct diagnosis should prevent incorrect treatment (increased anticoagulant). What patient, machine or catheter factors determine changes in blood flow, however, requires further study. A more comprehensive study determining the epidemiology of flow reductions is now needed. We are currently undertaking such a study.

In summary, we have developed a technique to continuously monitor and graphically display blood flow during CRRT. This technique reveals that set flow is inaccurate and that otherwise undetected blood flow reductions occur. Further research is now needed to study the epidemiology and clinical consequences of flow reductions.

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