Doppler Monitoring of Hemodialysis Grafts

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Abstract: Hemodialysis access deterioration leads to occlusion of the graft in an average of 11 months requiring the creation of a new access in a new location. A simple low cost Doppler method allows the measurement of graft flow rate and hemodynamic resistance during each dialysis session, providing early warning of immanent occlusive failure.

INTRODUCTION

Hemodialysis access shunts can be created in 6 convenient locations, two on each arm and one on each leg. The shunt directs arterial blood directly into the venous return, bypassing capillary beds. A normal shunt has a flowrate of approximately 1000 ml/min; normal cardiac output is 5000 ml/min. This high shunt flowrate is required to permit routing a portion of the bloodflow at a rate of 400 ml/min to the hemodialysis machine during the 4 hour dialysis sessions which occur three times per week. Half of the access shunts occlude within one year; 90% of the occlusions are due to a progressive stenosis on the venous end of the shunt. Half of those shunts with flowrates below 750 ml/min occlude within 8 months while only 10% of those with greater flowrates occlude in the same period. If the venous stenosis can be detected and revised prior to occlusion, the access can be preserved indefinitely. Many access shunts occlude unexpectedly because evaluation by X-ray angiography or by ultrasonic duplex/Doppler sonography is technically difficult and costly, resulting in a high threshold for evaluation.

This illustration shows a typical hemodialysis access

![Diagram of hemodialysis access](image)

A portion of the arterial blood passes through the access shunt. When the patient is not having dialysis, the flowrate at all three locations in the shunt, S, M and E, are equal. During dialysis, the flow through the arterial needle Ka is equal to the flow through the venous needle Kv. The shunt flow S = E = M + Kv.

One method of access monitoring is done during each dialysis, the measurement of the pressure in the needle which returns the blood to the venous circulation. In cases of venous stenosis, that pressure is elevated. Unfortunately, it is also possible to measure and elevated venous needle pressure due to positioning of the venous needle adjacent to the vessel wall. This introduces unacceptable variability into the measurement. Since 1994, a series of methods of determining the threshold and rate of recirculation of dialyzed blood backwards through the access have been developed. During recirculation, S = E < Ka = Kv so M < 0. All of the methods are complex, and therefore applied sparingly. We believe that CW Doppler ultrasound provides an alternative method for determining the recirculation threshold.

The purpose of this research project is to develop and test a simple low cost CW Doppler method of determining the volume flowrate and recirculation threshold in hemodialysis access which can be applied during each dialysis. By noting the deterioration in flowrate over time, appropriate intervention can be initiated.
MATERIALS AND METHODS

Recirculation, defined as reverse flow of blood in the segment between the needles, occurs when the pump flowrate exceeds the resting access flowrate. Ultrasonic Doppler is a convenient method to measure flow direction. In the simplest application of the new method, continuous wave (CW) directional Doppler waveforms are obtained from the access shunt between the needles. One waveform is obtained when the pump is off, (0 ml/min) a second waveform is obtained when the pump is running at normal speed (200 to 400 ml/min). If the graft flowrate exceeds the pump flowrate during both systole and diastole, then both waveforms will be in the same direction, the velocities with the pump on will be lower than the velocities with the pump off.

From the systolic and diastolic Doppler frequency shifts or Doppler velocities, the systemic blood pressure and the pump flowrate, the access flowrate $Q$ and resistance $R$ can be measured in systole and diastole.

$$Q_{access} = Q_{pump} \times V_{off} / (V_{off} - V_{on})$$

$$R = Q_{access} / BP$$

RESULTS

In most cases, the resistance in systole is greater than in diastole.

Negative resistance is puzzling.

DISCUSSION

The higher resistance in systole is probably due to turbulence limiting flowrate. The negative resistance may be due to needle reversal.