Ultrafiltration Techniques and CPB: What We Know and What We Think We Know

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INTRODUCTION

Today, the application of ultrafiltration with cardiopulmonary bypass (CPB) is commonplace. The myriad of ultrafiltration techniques can be characterized into two primary rationales: 1) volume management and 2) mediator-removal. These rationales have emerged successively during the development of ultrafiltration and influence the technical integration and use of the hemoconcentrator with the CPB circuit.

HISTORY

The Volume Management Rationale (1976–Present)

The initial use of ultrafiltration in conjunction with CPB was reported in 1976 as a way to concentrate the dilute extracorporeal circuit contents following bypass (1). Soon after, Darup et al. described the first use of ultrafiltration during CPB (2). The bypass circuit was found to be ideally suited for ultrafiltration as it offers easy access to the blood path and provides either a pump or a positive pressure site to drive blood through the hemoconcentrator. The application of ultrafiltration during CPB was initially reserved for the management of volume overload in patients with renal insufficiency and/or failure. However as the 1980s progressed this conventional ultrafiltration (CUF) technique became more widely adopted (3–7)

The ultimate fluid management/blood salvage ultrafiltration technique was first described by the Hospital for Sick Children in London (8). They reported on a modified ultrafiltration (MUF) technique which was used in the immediate post CPB period to concentrate the blood volume of their pediatric patients. By 1990, ultrafiltration was well accepted as an important adjunct to CPB that could fulfill a role in fluid balance control and blood conservation.

The Mediator-Removal Rationale (1990–present)

While conventional and modified ultrafiltration techniques were experiencing an ever increasing clinical acceptance during the early 1990s some clinicians theorized that there was an additional benefit to ultrafiltration. Coraim et al. reported improved hemodynamics in patients following cardiac surgery when continuous arterio-venous hemofiltration (CAVH) was applied. They attributed this observation to the convective removal of myocardial depressant substances (9). Further work by researchers in a septic animal model suggests that left ventricular function improves with ultrafiltration and volume replacement (10). In 1992 a study by Grootendorst et al. demonstrated that when endotoxemic pigs underwent high volume ultrafiltration (6 L/h in an ~80 lbs pig), cardiac performance improved (11). This improvement did not occur when the blood passed through the hemoconcentrator with the ultrafiltrate line clamped. In a follow-up study, the same researchers collected and infused the ultrafiltrate from endotoxemic pigs into control animals and found that myocardial performance became depressed in the healthy pigs (12). The work of these researchers fuelled the emergence of the conceptual framework that ultrafiltration was doing more than simply removing free water and electrolytes, but, rather, it also removes potential deleterious substances from the blood thereby improving the patient's status.

Given the myriad of ultrafiltration techniques that have been developed and the debate over the therapeutic effect of large volume ultrafiltration, the two-fold purpose of this presentation is to review and discuss various ultrafiltration techniques and to demonstrate the effectiveness of zero-balance ultrafiltration (ZBUF) at reducing the mortality in an acute animal model (13).

METHODS

Following committee approval, a control and treatment group consisting of Yorkshire pigs (30–40 kg) were anesthetized, ventilated, and then cannulated via the right femoral vein and artery and exposed to CPB for 60 minutes. Following CPB, a low-dose endotoxin (1 g/kg) was administered and the animals were monitored for 3.5 hours. The treatment group (n = 5) received high-volume Z-BUF (122 ± 41 ml/kg) and the control group (n = 5) did not. Hemodynamics, blood gases, and pulmonary functions were measured before, during, and after CPB.

RESULTS

During the experimental time course there were no differences in CO, MAP, Na^+, K^+, Ca^{++}, and IL-8 concentrations between groups. However, in the control group, the PaO_2 decreased (238 ± 60 mmHg vs. 78 ± 40 mmHg*) and the pulmonary compliance decreased (32.2 ± 5.9 mmHg vs. 8.4 ± 4.2 mmHg*) significantly compared to the treatment group. These same parameters were unchanged in the treatment group. Furthermore, histologic examination of lung biopsy showed significantly increased leukocyte infiltration and tissue density in the control group.

Disclaimer: This mini manuscript represents a vignette of the content materials and references originally prepared for a text book chapter authored by Searles and Darling for a book titled: *On Bypass: Advanced Techniques in Cardiopulmonary Bypass*, Editors: Oz, Mongero, and Beck. Publisher = Humana Press. Scheduled for publication in 2006.

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CONCLUSION

This result suggests that Z-BUF improves the pulmonary function in this model of severe lung injury and may be an effective tool in attenuating the CPB derived inflammatory process.

SUMMARY

Unfortunately there have been very few prospective randomized studies comparing the clinical outcomes of patients treated with large volume ultrafiltration (14,15). Given the shortage of impressive clinical outcome data and the varying results of mediator removal studies, the application of ultrafiltration as a therapeutic technique is still a controversial topic. A few researchers have suggested that different membrane materials may have significantly different mediator removal potential (16–18). One important future direction for research in this area should include a comprehensive comparison of different membrane materials with regard to their clinical performance.

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Glucose and Outcome After Cardiac Surgery: What are the Issues?

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Hyperglycemia frequently occurs during the conduct of cardiopulmonary bypass (CPB) for cardiac surgery. In addition to the exogenous administration of glucose containing solutions [most notably with dextrose containing cardioplegia as well as variably in the pump prime] (1), the stress response to both surgery and CPB marked by significant increases in circulating catecholamines (epinephrine and norepinephrine) and cortisol (2) results in significant peripheral insulin resistance and marked increases in blood glucose concentrations (3–5). Hyperglycemia, defined arbitrarily as a serum glucose >200 mg/dL occurs in as many as 75% of patients during surgery with patients with pre-existing diabetes mellitus having an even higher incidence (6).

Attenuating this hyperglycemic response to cardiac surgery has proven difficult, with even high insulin doses more often than not failing to return glucose to normal levels during surgery. Part of this failure is reflective of the significant anti-insulin effects of elevated circulating catecholamines and cortisol (7), and partly it is related to the impaired ability of insulin to transport glucose intracellularly under the hypothermia that is frequently used during the normal conduct of cardiac surgery (3). Indeed, Chaney et al. found that not only was normoglycemia difficult to attain during cardiac surgery, but that with large insulin doses administered during surgery, a high incidence of hypoglycemia in the post-bypass period posed a significant risk (8). In addition, excessive insulin can also result in hypokalemia due to its enhancement of potassium transmembrane transport