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Body fluid compartment changes following cardiopulmonary bypass in dogs

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Abstract. To investigate whether pulsatile perfusion affects postoperative edema, we examined weight, total body water (TBW), and extracellular fluid (ECF) following cardiopulmonary bypass (CPB) in dogs using three different perfusion systems. Fourteen dogs were divided into three groups differing only in the perfusion system used: Sarns nonpulsatile and pulsatile roller pumps and a University of Texas pulsatile pump. Weight, TBW, and ECF were measured preoperatively and on postoperative days (POD) 1, 3, and 7. No significant differences were seen in body weight, TBW, or ECF between groups. Body weight varied within 10% of preoperative values. TBW (percent of body weight) rose significantly ($P = 0.005$) to 72% on POD 3 and 7. ECF (percent of body weight) rose to 58% by POD 7 ($P = 0.008$). These three perfusion systems produced no differences in the pattern of postoperative body fluid distribution after CPB, suggesting that there is no advantage to pulsatile perfusion for the purpose of decreasing postoperative edema.

Key words: Body fluid compartments – Cardiopulmonary bypass – Perfusion systems

Introduction

Postoperative edema following cardiopulmonary bypass (CPB) can cause cardiac and/or pulmonary dysfunction, which in turn contributes significantly to the morbitity of cardiac surgery. Small children may be particularly susceptible to these complications. Elevation of measured extracellular fluid (ECF) has been repeatedly demonstrated following standard nonpulsatile CPB [2, 5, 13]. Considerable controversy exists, however, regarding the effect of pulsatile versus nonpulsatile perfusion on a number of physiologic changes accompanying CPB [9]. Indirect evidence suggests that more edema results following nonpulsatile bypass, but little specific information is available demonstrating the dependence of body fluid shifts on the type of perfusion system employed. To investigate this relationship we measured changes in weight, total body water (TBW), and ECF following CPB in young dogs using three different perfusion systems.

Methods

Fourteen beagle dogs (6 weeks old, av wt 10 kg) were divided into three groups differing only in the perfusion system used: group I–Sarns nonpulsatile roller pump; group II–Sarns pulsatile roller pump; group III–University of Texas externally-valved, piston-compressed, conduit pulsatile pump. Other components of the circuit included a Bentley neonatal bubble oxygenator and a heat exchanger. The circuit was primed with a blood-crystalloid mixture (approx. hematocrit = 20%) with pH corrected to 7.4 prior to initiation of bypass. Perioperative gentamicin was administered and pentobarbital anesthesia was used for all procedures. Animal welfare policies and standards of the American Association for the Accreditation of Laboratory Animal Care were followed in conjunction with the animal experimentation. Animals were intubated and allowed to breathe spontaneously until the chest was opened. Femoral artery and vein cannulation was performed for monitoring, blood sampling, and fluid infusion. Venoarterial bypass was instituted following heparinization (200 U/kg) by performing arterial cannulation via the right common carotid artery with the catheter tip placed in the aortic arch, confirmed at autopsy, and venous cannulation via the right atrium using a small right thoracotomy. Near total venous diversion was

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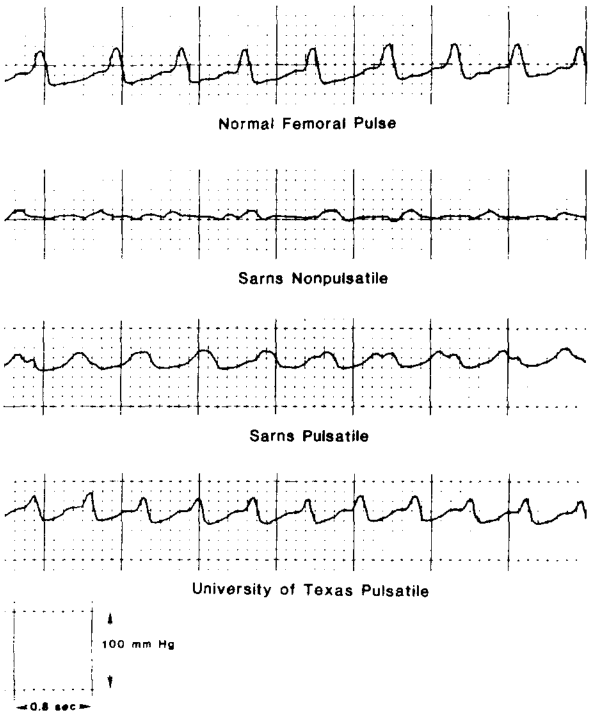

Fig. 1. Femoral pulse wave forms for normal dog, Sarns nonpulsatile pump, Sarns pulsatile pump, and University of Texas pulsatile pump

confirmed by visually identifying an empty right atrium and by inspection of the femoral pulse contour prior to institution of pulsatile bypass, when used.

Following the initiation of stable CPB the animals were cooled to 28°C and maintained at that temperature for 90 min, rewarmed to 39°C, than decannulated. Circuit flow was maintained at 100 ml/kg per minute during warm perfusion with a mean arterial pressure of 60–70 mmHg. For the pulsatile flow groups, pulse pressure was kept between 20 and 30 mmHg (Fig. 1). Sodium bicarbonate was given, if needed, to maintain a pH between 7.3 and 7.4. Postoperatively the animals were allowed food and water ad lib. Weight, TBW, and ECF were

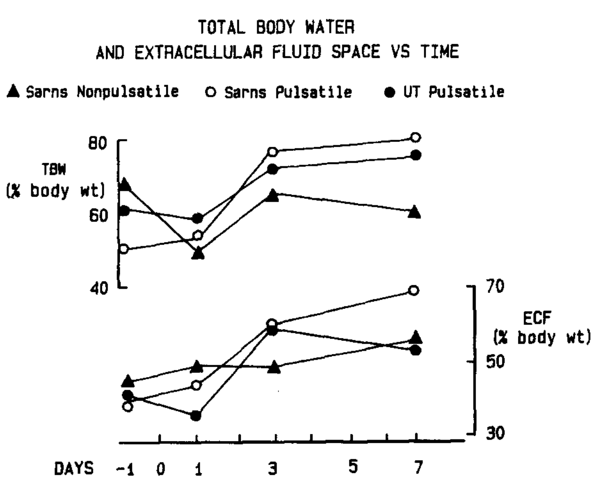

Fig. 2. Comparison of body fluid space changes with three different perfusion systems

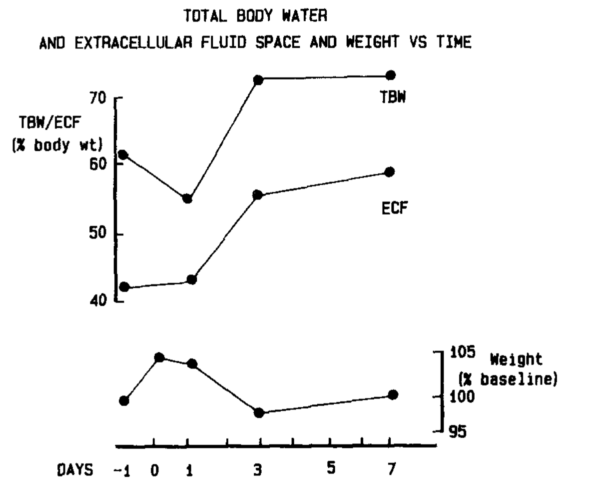

Fig. 3. Body fluid space and weight changes for all animals combined ($n = 14$)

measured preoperatively and on postoperative days (POD) 1, 3, and 7. TBW and ECF were determined by measuring the distribution of deuterium oxide [14] and sodium bromide [7], respectively, allowing a 3-h equilibration period following isotope injection. Data was analyzed using Student's t-test with $P < 0.05$ considered significant.

Results

The trends in TBW and ECF changes in each group are depicted in Fig. 2. While both fluid compartments were seen to enlarge in all groups postoperatively, no changes reached statistical significance. Likewise, no significant differences could be demonstrated in weight, TBW, or ECF between the groups. Combination of the data for all 14 animals (Fig. 3) shows that body weight varied within 10% of preoperative values with a peak on POD 1, a low on POD 3, and a return to preoperative levels by POD 7. TBW, expressed as percent of body weight, fell from 61% to 55% from preoperatively to POD 1, then rose to 72% on POD 3 and POD 7. This postoperative rise was significant ($P = 0.005$). The ECF space rose from 42% of body weight preoperatively to 58% by POD 7. This rise was also significant ($P = 0.008$).

Discussion

In this model of CPB in young dogs, designed to resemble a typical operative course of a child undergoing cardiac surgery, no advantage to pulsatile perfusion could be demonstrated for the purpose of decreasing postoperative ECF expansion. This correlated with the lack of evident differences in the modest amout of peripheral edema noted clinically in each group. A postoperative increase of both TBW and ECF was demonstrated for the group as a whole but did not reach statistical significance within each subgroup, possibly due to small sample sizes. Earlier studies in which these fluid spaces were directly measured following standard, nonpulsatile CPB have demonstrated a consistent rise in ECF postoperatively, as seen here, but a less definable change in TBW [2, 5, 13]. These shifts of body fluid have been shown to be most pronounced in patients with a history of preoperative congestive heart failure or when hemodilution is used [6]. One study, looking only at functional changes and myocardial associated with CPB, showed that newborns were much more susceptible to these changes [12]. In many centers hemodilution is avoided in small children because of resultant problems with postoperative edema [3].

In most studies comparing pulsatile and nonpulsatile perfusion, indirect evidence has supported the conclusion that more edema occurs following nonpulsatile perfusion. This evidence takes the form of increased fluid requirements, higher transfusion volumes, lower urine output and creatinine clearance, and greater evident peripheral edema, all seen in the nonpulsatile groups [8–10]. Other studies, however, have failed to show significant differences between the two types of perfusion in terms of fluid balance, particularly when high-flow perfusion was employed [4, 11].

These findings are summarized in an excellent review by Hickey et al. [9]. Elsewhere in this review Hickey emphasizes that because of the lack of definition and documentation of the nature of the perfusion used in different studies, meaningful comparisons are difficult to make. Therefore, considerable controversy continues regarding the differences between pulsatile and nonpulsatile perfusion. Bartlett [1] points out that many of the demonstrated differences between these two types of perfusion are related to the flow rate used. No significant difference is noted when flows close to the expected normal cardiac output are employed; however, at flow rates closer to 50% of expected cardiac output some advantage is demonstrated with pulsatile perfusion.

The aim of this study was to directly measure the changes in TBW and ECF following pulsatile and nonpulsatile perfusion in a model resembling a child undergoing cardiac surgery. Under the conditions employed in this study, which included flows near expected cardiac output and modest hemodilution, we found no advantage to pulsatile perfusion for the purpose of decreasing edema following cardiopulmonary bypass.

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