Abstract: At the turn of the millennium, perfusion teaching programs are faced with significant difficulties. The number of students in pediatric perfusion training has increased, and more importantly, the number of pediatric open-heart procedures has decreased because of a variety of reasons. Hence, they could barely satisfy the minimum requirements of pediatric cases established by the teaching programs. The idea of “a teaching circuit” that could reproduce and simulate cardiopulmonary bypass was designed. The trainee is able to manipulate the cardiopulmonary bypass circuit according to patient responses, to perform perfusion related-maneuvers in establishing and maintaining hemodynamic stability. The aim of this study was to simulate a patient on CPB, maintain stability during varying clinical situations, and then to wean the patient off CPB. The equipment used was reusable and nonsterile. Keywords: teaching, cardiopulmonary bypass, cardiac simulator.

MATERIALS AND METHODS

Material and Circuit Setup

The perfusion-training simulator consists of two separate circuits: a patient circuit and a pump circuit, which are interconnected. The patient circuit consists of a closed system utilizing a 1/4" load sensitive pump (Figure 1), a 250 mL bag (I) to simulate systemic vascular resistance (SVR) and pulse pressure via insertion of a 12-mL intra-aortic balloon (IAB) inside the 250 mL bag. An adjustable 1000 mL bag (R) to simulate preload and central venous pressure (CVP). The pump circuit consists of an open system utilizing a roller pump (A), membrane oxygenator (C) with hard shell reservoir (V), and an arterial line filter (E). The two circuits are interconnected by the arterial side (H) and the venous side (T).

All the lines in this circuit are 1/4" to replicate flow rates associated with patients in the 5–10 kg range. If higher flow rates are required, larger tubes, arterial filters, oxygenators, IAB and bladder bag for IAB should be used. Appropriate connectors should be selected according to institutional preferences and requirements. Such emergency situations as split raceway, oxygenator change out, loss of electrical power, and so forth can also be simulated. We feel that this provides the trainee with experience in dealing with a wide variety of clinical situations. The circuit may be used to evaluate the performance of the trainee during and at the end of their training program.
For the insertion of the IAB, a blue perforated rubber cap from a central line kit was used to cover the loose end of the 1/4" connector. The IAB is inserted through the hole without any problems, and no leaks were observed after taping the blue cap and IAB line to the connector to secure them. See Figure 1 for schematic of circuit.

**Figure 1.** Perfusion-training simulator.

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**Priming and Operating the System**

Two experienced perfusionists are required. One to control the patient side of the circuit and another to supervise the student. Set up all the equipment in the appropriate holders, prime with 1.5 L of your choice, and debubble. The 1000-mL bag, R (Figure 1), can be adjusted for volume content by folding it down and clamping it with a tubing clamp. This will allow you to mimic smaller patients, because less volume will be required to increase the CVP. When you go on bypass, this bag should be free of air. Turn off purge line stopcock, sampling manifold, and recirculation line. With little volume in the 1000-mL bag and all the pumps off, connect all pressure lines, zero
them, and then turn stopcocks to record arterial and CVP. Patient pressure should be connected to a pressure bag. Clamp venous line, start arterial pump, A fill 1000-mL bag to get CVP around 7 mmHg, and clamp arterial line. Connect a cardiac simulator (rate 100-120) to the monitor and to an intra-aortic balloon pump (IABP). Start IABP to electrocardiogram (ECG) settings. Start the load-sensitive pump, N to 1000-1500 rpm. You should get a flow of around 750 mL/min. Adjust augmentation and timing on IABP (5). This is what the “patient side” of the system is doing.

Unclamp arterial line, start main pump, and open venous line. Partial clamp, Y on the arterial side, after the line pressure manometer, to replicate line pressure. CVP will drop below 0 mm Hg, and the load-sensitive pump flow will drop. It reproduces initiation of CPB very well. Stop the IABP, and clamp the outlet of the load-sensitive pump, because the heart is empty. Administer cardioplegia in a bucket while partially clamping the cardioplegia line to create resistance. Use the sucker and vent to recuperate the volume. Gradually decrease the cardiac simulator rate, and then turn it off.

When the cross clamp is removed, start the cardiac simulator slowly (50–75/min), start the IABP, release the clamp on the outlet of the load-sensitive pump, and release the clamp on line, L (Figure 1). Increase simulator rate and adjust IABP. The student closes all shunts, starts leaving volume behind to fill the patient until the CVP reaches 8–10 mm Hg, and the blood pressure is acceptable. The student clamps the venous line, stops the pump, and clamps the arterial line. CPB is now ceased.

Emergencies, blood gas analysis, and drug requirements during the procedure are performed according to the institution’s protocol. Cooling and rewarming, MUF, hemoconcentration, suction, and venting do not require indications from the patient side of the circuit. Table 1 shows examples of manipulations by instructor and student.

RESULTS

The patient side circuit, when controlled by experienced perfusionists, reproduced such clinical features as changes in arterial pressure (systolic/diastolic), CVP that would affect systemic pressure when it was increased or decrease, on a regular basis. With well-placed clamps, the clinical instructor could imitate arterial pressure changes and variability in venous return.

A stopcock placed near the 1000 mL, R bag, allows the clinical instructor to vary the volume of the circuit; that is, bleeding. That will affect CVP and arterial blood pressure. The circuit incorporates all components of a normal CPB system; students can gain confidence and experience with smaller patients and improve their skills on initiation and termination of bypass, cardioplegia delivery, maintenance of bypass (pressure/drugs/ABG-electrolytes), and emergencies.

However, this circuit has several disadvantages. We were unable to simulate venous air locks and introduce air on the arterial side.

DISCUSSION

An effort was taken to design and develop a reusable and disposable CPB circuit for trainee perfusionists. Trials, using this circuit have demonstrated that it is possible to simulate clinical situations especially in the pediatric population. This circuit can also be modified and adapted to simulate adult cases.

The circuit can also be an invaluable tool for cardiac surgical residents in training and other disciplines associated with perfusion. The circuit can be used repeatedly by trainees to practice most of the basic aspects of CPB, allowing them to gain confidence, increase their skills, and better understand the principles and concepts of pediatric perfusion. The current design will, however, only allow the basic concepts of CPB. Complex congenital heart procedures pose a challenge even to the experienced perfusionists.

Future considerations would include more complex aspects and computer regulation of the circuit. To our knowledge, there are presently no dedicated and reusable
circuits available for training perfusionists, which would give them an opportunity to practice perfusion-related techniques before being exposed to the actual clinical situation and also be used for their evaluation.

REFERENCES


