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Techniques and Applications

A Reusable Training Circuit for Cardiopulmonary Bypass

Guy Millette, CPC; Nihal Weerasena, MD; Garry Cornel, MD; Lothar Broecker, CCP

Children's Hospital of Eastern Ontario, Ottawa, Ontario, Canada

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. *JECT. 2002;34:285–288*

Because the number of pediatric cardiac procedures performed has shown a decline, and because the number of complex neonatal procedures within that group has increased, the trainee perfusionist is finding it difficult to get the expertise required within the short period of time in training (1). We decided to design a training circuit that could simulate clinical situations. This would provide the trainee greater exposure and increase their confidence in managing cardiopulmonary bypass (CPB). This disposable and reusable circuit was designed for teaching purposes only. It will allow the trainee to perform both pediatric and, if required, adult cases using this circuit. The trainee is able to establish, maintain, and terminate CPB. The circuit can also be maneuvered to such clinical situations as: the delivery of cardioplegia, ultrafiltration (2), and modified ultrafiltration (MUF) (3,4). We describe here the main components of CPB circuit as it pertains to a pediatric circuit, without incorporating suction and/or venting lines, autotransfusion, ultrafiltration, MUF circuit, and cardioplegia delivery system. These techniques can be added to the basic circuit if required. The circuit also has the flexibility to be modified 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.

Address correspondence to: Guy Millette, Children's Hospital of Eastern Ontario, 401 Smyth Road, Ottawa, Ontario KIH 8LI, Canada. E-mail: millette@ cheo.on.ca
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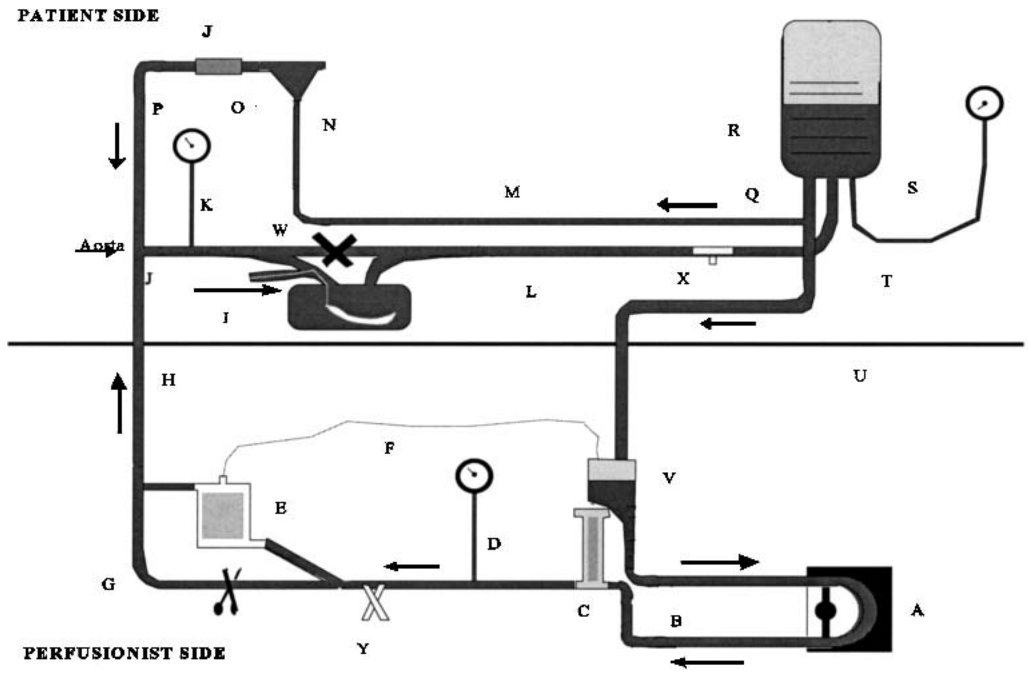
MATERIALS AND METHODS

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 tubing size. A 4″ × 3/8″ piece of tubing with 1/4″ × 3/8″ connector should be included to connect the venous line if your venous reservoir inlet is 3/8″.



A-Main arterial pump head
B-Raceway tubing(240 cm)
C-Oxygenator
D-Arterial line pressure gauge
E-Arterial filter
F-Arterial filter purge line
G-Arterial filter bypass loop
H-Arterial line going to aorta(60 cm)
I-250cc bag to insert IAB
*J-IAB-**pulsatile flow(systole-diastole)***
K-patient pressure gauge
L-Systemic resistance(60 cm)
M-Line from 1000cc bag to load sensitive pump(120 cm)
N-Load sensitive pump
O-Flow probe
P-Line from flow probe to aorta(45 cm)
Q-Line to join lines M and T(15 cm)
*R-1000cc soft bag-**right atrium***
S-RA pressure gauge
T-Venous line
U-Operative field sterile drape
V-Venous reservoir
W-Hypotension line
X-1/4-1/4 with luer
Y-Partial clamp to create line resistance

Figure 1. Perfusion-training simulator.

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.

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 institutions'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.

Table 1. Manipulations.

Patient Side (Instructor's Manipulations)	Perfusion Side (Student's Manipulations)
1. **To replicate low perfusion pressure** (due to hypotension), release clamp on line W.	**Pharmacologic maneuvers** (vasoconstrictor) Because we're already at full flow, increasing flow rate will have minimal effects
Reclamp line W for applicable student response.	Perfusion pressure normalizes—No further action from student
2. **To replicate high perfusion pressure,** partially clamp line L.	**Pharmacological maneuvers** (vasodilators) **Talk to anesthetist** (patient may be light).
Unclamp line L for applicable student response.	Perfusion pressure normalizes–No further action by student
3. To increase arterial line pressure, partially clamp line J.	Decreases flow Checks for arterial line obstruction Communicates concerns to surgeon
Unclamp line J for applicable student response.	Line pressure normalizes with appropriate student action.
4. To suddenly decrease venous return, partially clamp line T.	Decreases flow Checks for venous line obstruction Communicates concerns to surgeon
Unclamp line T for applicable student response.	Venous return normalizes with appropriate student action

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.

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