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A Quick Reference Tool for Goal-Directed Perfusion in Cardiac Surgery

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Abstract: Traditionally, blood flow rates on cardiopulmonary bypass are based primarily on a formula that matches cardiac index to the patient's body surface area (BSA). However, Ranucci and associates in the Goal-Directed Perfusion Trial (GIFT) trial have shown that coupling the BSA with delivery of oxygen (DO_2), known as goal-directed perfusion (GDP), may be a safer approach to determine appropriate blood flows. The objective of this study was to create a GDP reference tool that would allow perfusionists to quickly determine the lowest acceptable blood flow needed to provide a patient of any BSA with a satisfactory DO_2 without the need for additional dedicated technology. We approached this problem by deriving a formula for flow (L/min), based on BSA, oxygen content of the blood, and a minimum DO_2 of 280 $mL \cdot min^{-1} m^{-2}$. A quick reference GDP chart was created based on the derived formula, requiring only the patient's BSA and hemoglobin level to determine a safe minimum flow rate. The proposed tool allows any cardiac surgery center to adopt the GDP technique, even in the absence of instantaneous DO_2 monitoring equipment.
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OVERVIEW

Ensuring that patients maintained on cardiopulmonary bypass (CPB) receive optimal blood flow during their surgical procedure is an essential goal of the cardiac surgery team. Historically, CPB flows have been largely based on the experience of the perfusionist, monitoring of mixed venous and cerebral blood saturations, or a formula based on the cardiac index (e.g., 2.4 $L \cdot min^{-1} \cdot m^{-2}$) multiplied by the body surface area (BSA) of the patient. Initial blood flow targets are traditionally based on cardiac indexes of 2.2–2.5 $L \cdot min^{-1} \cdot m^{-2}$ (1). However, pump flow based solely on a cardiac index does not necessarily ensure the satisfactory delivery of oxygen (DO_2) to the patient's tissues. Even with acceptable indexed flows, if the oxygen content of the arterial blood (CaO_2) is low, the patient will be exposed to a perfusion-oxygen delivery mismatch with physiologic consequences similar to hypoperfusion. This may lead to metabolic acidosis, hyperlactatemia, and end-organ ischemia, resulting in higher rates of morbidity and mortality (2,3).

To truly know whether blood flow on bypass is adequate, it must be coupled with the CaO_2 (4). This focus on DO_2 is known as goal-directed perfusion (GDP). Whereas traditional perfusion techniques only achieve a high DO_2 in 50% of cases, a GDP approach does so in upward of 90% of cases, with a consequent reduction in acute kidney injury rate of 40% (5). Currently, practicing GDP requires either the adoption of expensive dedicated DO_2 monitors (e.g., LivaNova GDP™ monitor and CONNECT™ software [LivaNova, London, UK]) or that the perfusionist perform complex and potentially distracting calculations while on bypass. The objective of this project was to create a reference tool for perfusionists that would allow them to quickly determine the lowest acceptable blood flow needed to provide an adequate DO_2, requiring only a patient's BSA and current hemoglobin (Hgb) level.

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DESCRIPTION

This objective could be realized by first deriving an appropriate formula for flow (L/min), based on BSA, CaO_2, and a satisfactory DO_2 index (DO_2i). In the GIFT multicenter randomized controlled trial, Ranucci et al. compared a GDP strategy with a control arm of patients receiving a pump flow rate based on a cardiac index of 2.4 $L \cdot min^{-1} \cdot m^{-2}$. The trial showed that a DO_2i greater than or equal to 280 $mL \cdot min^{-1} \cdot m^{-2}$ was independently associated with better patient outcomes, specifically lower rates of stage 1 acute kidney injury. In an analysis of patients with a CPB time between 1 and 3 hours, the differences in favor of a GDP strategy with a DO_2i of 280 $mL \cdot min^{-1} \cdot m^{-2}$ were even more pronounced (6).

Using the DO_2i of 280 $mL \cdot min^{-1} \cdot m^{-2}$, and the known formulas for DO_2 and CaO_2, the following blood flow (Q_{blood}) formula was derived:

$$CaO_2 = (Hgb \times 1.34)(SaO_2/100) + (PaO_2 \times 0.0031),$$

$$DO_2 = Q_{blood} \times 10 \times CaO_2,$$

$$DO_2i = DO_2/BSA,$$

$$280 = Q_{blood} \times 10 \times Cao_2/BSA,$$

$$Q_{blood} = 280 \times BSA/[(Hgb \times 1.34)(SaO_2/100) + (PaO2 \times 0.0031)] \times 10.$$

To simplify the formula, two assumptions were made. The first assumption was that the arterial blood delivered to the patient will be 100% saturated (SaO_2 = 100). The second assumption was that the partial pressure of oxygen (PaO_2) in the arterial blood will be ≥ 200 mmHg (PaO_2 = 200).

$$Q_{blood} = 280 \times BSA/[(Hgb \times 1.34) + 0.62] \times 10.$$

With this simplified formula, a quick reference chart was generated, showing the minimum flow (L/min) required to achieve a safe DO_2i (280 $mL \cdot min^{-1} \cdot m^{-2}$), only requiring knowledge of the patient's BSA and Hgb level (Table 1).

DISCUSSION

Studies have shown that blood flows on CPB that do not provide an adequate DO_2 will result in increased risk of acute renal injury and hyperlactatemia (7,8). A direct comparison of GDP-based flow with cardiac index–based flow shows that commonly used cardiac indexes often underestimate the flow required to achieve a DO_2i of 280 $mL \cdot min^{-1} \cdot m^{-2}$, especially as Hgb values decrease (Table 2).

The tool developed by our group will allow cardiac surgery centers to determine patient pump flows based on DO_2 requirements (GDP), even in the absence of instantaneous DO_2 monitoring equipment. Although this

Table 1. The VA Boston quick reference tool for goal-directed perfusion.

	Hgb (g/dL)												
BSA (m^2)	7.0	7.3	7.7	8.0	8.3	8.7	9.0	9.3	9.7	10.0	10.3	10.7	11.0
1.50	4.2	4.0	3.8	3.7	3.6	3.4	3.3	3.2	3.1	3.0	2.9	2.8	2.7
1.60	4.5	4.3	4.1	4.0	3.8	3.7	3.5	3.4	3.3	3.2	3.1	3.0	2.9
1.70	4.8	4.6	4.4	4.2	4.1	3.9	3.8	3.6	3.5	3.4	3.3	3.2	3.1
1.80	5.1	4.9	4.6	4.5	4.3	4.1	4.0	3.9	3.7	3.6	3.5	3.4	3.3
1.85	5.2	5.0	4.7	4.6	4.4	4.2	4.1	4.0	3.8	3.7	3.6	3.5	3.4
1.90	5.3	5.1	4.9	4.7	4.5	4.3	4.2	4.1	3.9	3.8	3.7	3.6	3.5
1.95	5.5	5.3	5.0	4.8	4.7	4.5	4.3	4.2	4.0	3.9	3.8	3.7	3.6
2.00	5.6	5.4	5.1	4.9	4.8	4.6	4.4	4.3	4.1	4.0	3.9	3.7	3.7
2.05	5.8	5.5	5.3	5.1	4.9	4.7	4.5	4.4	4.2	4.1	4.0	3.8	3.7
2.10	5.9	5.7	5.4	5.2	5.0	4.8	4.6	4.5	4.3	4.2	4.1	3.9	3.8
2.15	6.0	5.8	5.5	5.3	5.1	4.9	4.8	4.6	4.4	4.3	4.2	4.0	3.9
2.20	6.2	5.9	5.6	5.4	5.3	5.0	4.9	4.7	4.5	4.4	4.3	4.1	4.0
2.25	6.3	6.1	5.8	5.6	5.4	5.1	5.0	4.8	4.6	4.5	4.4	4.2	4.1
2.30	6.5	6.2	5.9	5.7	5.5	5.3	5.1	4.9	4.7	4.6	4.5	4.3	4.2
2.35	6.6	6.3	6.0	5.8	5.6	5.4	5.2	5.0	4.8	4.7	4.6	4.4	4.3
2.40	6.7	6.5	6.2	5.9	5.7	5.5	5.3	5.1	4.9	4.8	4.7	4.5	4.4
2.45	6.9	6.6	6.3	6.1	5.9	5.6	5.4	5.3	5.0	4.9	4.8	4.6	4.5
2.50	7.0	6.7	6.4	6.2	6.0	5.7	5.5	5.4	5.1	5.0	4.9	4.7	4.6
2.60	7.3	7.0	6.7	6.4	6.2	5.9	5.8	5.6	5.4	5.2	5.1	4.9	4.7
2.80	7.9	7.6	7.2	6.9	6.7	6.4	6.2	6.0	5.8	5.6	5.4	5.2	5.1
3.00	8.4	8.1	7.7	7.4	7.2	6.9	6.6	6.4	6.2	6.0	5.8	5.6	5.5

The flow shown (L/min) for a given BSA and Hbg is the minimum required to achieve a DO_2i of 280 $mL \cdot min^{-1} \cdot m^{-2}$. All values assume 100% arterial saturation and a PaO_2 of 200 mmHg.

Table 2. Comparison of flow requirements (L/min) as determined by goal-directed perfusion versus the flow requirements based on cardiac index for patients of the same BSA.

	Goal-Directed Perfusion–Based Flow					Cardiac Index–Based Flow		
	Hgb (g/dL)					CI		
BSA (m^2)	7.0	8.0	9.0	10.0	11.0	2	2.2	2.4
1.50	4.2	3.7	3.3	3.0	2.7	3	3.3	3.6
1.60	4.5	4.0	3.5	3.2	2.9	3.2	3.5	3.8
1.70	4.8	4.2	3.8	3.4	3.1	3.4	3.7	4.1
1.80	5.1	4.5	4.0	3.6	3.3	3.6	4	4.3
1.90	5.3	4.7	4.2	3.8	3.5	3.8	4.2	4.6
2.00	5.6	4.9	4.4	4.0	3.7	4	4.4	4.8
2.10	5.9	5.2	4.6	4.2	3.8	4.2	4.6	5
2.20	6.2	5.4	4.9	4.4	4.0	4.4	4.8	5.3
2.30	6.5	5.7	5.1	4.6	4.2	4.6	5.1	5.5
2.40	6.7	5.9	5.3	4.8	4.4	4.8	5.3	5.8
2.50	7.0	6.2	5.5	5.0	4.6	5	5.5	6

equipment is effective, it is also prohibitively expensive for many cardiac surgery programs. Although instantaneous monitors provide an absolute DO_2 value at any given moment, all a perfusionist really needs to know is that the blood flow at any given moment is higher than the minimum threshold needed to provide a safe DO_2. The proposed tool provides the perfusionist with that threshold.

A limitation of our tool is the assumptions that were made to simplify the formula used to develop it. To ensure its accuracy, arterial blood gases should be routinely monitored to confirm that the assumptions are correct. The first assumption was that the SaO_2 will be 100% on bypass. We believe that this is a reasonable assumption because only in the face of an infrequent event, such as an oxygenator failure, would this not be true. The second assumption was that the PaO_2 of the blood will be $\geq$ 200 mmHg while on bypass. This number was chosen after Fontes et al. (9) reported in 1,018 patients undergoing CPB that a PaO_2 on bypass between 150 mmHg and 250 mmHg was not associated with any postoperative neurocognitive decline. Furthermore, the PaO_2 is multiplied in the equation by a factor of .0031 (the solubility coefficient of oxygen in plasma). This curtails the PaO_2 effect on the calculated flow requirement. For example, a PaO_2 of 150 mmHg, instead of 200 mmHg, only increases the flow requirement by .05 L/min.

GDP has been shown to improve oxygen delivery during CPB and reduce postoperative complications. This GDP tool can be immediately used by any cardiac surgery center to quickly and reliably calculate flow rates consistent with GDP.

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