

Geometry, Shunt and Recirculation in Hollow-Fiber Oxygenators

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Abstract

In extracorporeal circulation, hollow-fiber oxygenators are usually evaluated by gas transfer, pressure drop, and priming volume, but shunt and recirculation also critically affect performance. Shunt refers to blood bypassing effective fiber contact, while recirculation involves internal looping within the device, both altering oxygen transfer, hemocompatibility, and embolic safety. Geometry strongly influences these dynamics: cylindrical, plate-type, spiral, and radial designs each present benefits and risks of preferential channels, stagnation, or internal loops. Monitoring inlet and outlet flows provides a simple way to estimate shunt fraction, with values above 5–10% indicating clinically relevant losses. Pump technology further modulates these effects, as roller pumps deliver fixed flow while centrifugal pumps introduce preload- and afterload-dependent variability. Drawing a parallel to physiological shunts, quantifying these hidden flows may improve oxygenator assessment and perfusion safety, linking device design, pump type, and monitoring to more effective extracorporeal support.

Keywords: Hollow-fiber oxygenator, Shunt fraction, Recirculation, Perfusion monitoring, Blood flow dynamics

Dear Editor

In clinical extracorporeal circulation, hollow-fiber oxygenators are usually evaluated for long-term performance on gas transfer capacity, pressure drop, and priming volume. However, the phenomena of *shunt fraction* and *recirculation* are equally relevant to the perfusionist's daily practice. The *shunt* may be defined as the portion of blood that traverses the device with limited or no exposure to the functional fiber surface, while *recirculation* represents blood volume that loops internally within the fiber bundle, the heat exchanger, or the arterial filter before returning to forward flow. These hidden dynamics directly influence oxygen transfer, pressure readings, hemocompatibility, and embolic safety [1]. The **geometry of the oxygenator** is one of the key determinants of shunt and recirculation. **Cylindrical configurations** guide blood longitudinally or radially around the fiber bundle, promoting relatively uniform flow but also prone to creating preferential channels of low resistance. **Parallelepiped or plate-type designs** distribute blood in a rectangular housing, often in cross-flow fashion, increasing mixing and surface contact, though sometimes generating stagnation zones at the periphery [2]. **Spiral-wound geometries**, where fibers are packed in helical fashion, provide compact housings with low pressure drops, but can favor internal recirculation paths if the inlet distribution is not perfectly balanced. In some designs, **radial or elliptical flow arrangements** are employed to enhance homogeneity, yet these too may create high-shear focal regions and potential internal loops. The **heat exchanger** and the **arterial filter** also contribute, with polymeric or metallic exchangers shaping resistance and shear, and filter meshes inevitably generating vortices that may prolong bubble residence or alter embolic clearance [3]. Beyond geometry, the **role of monitoring** becomes crucial.

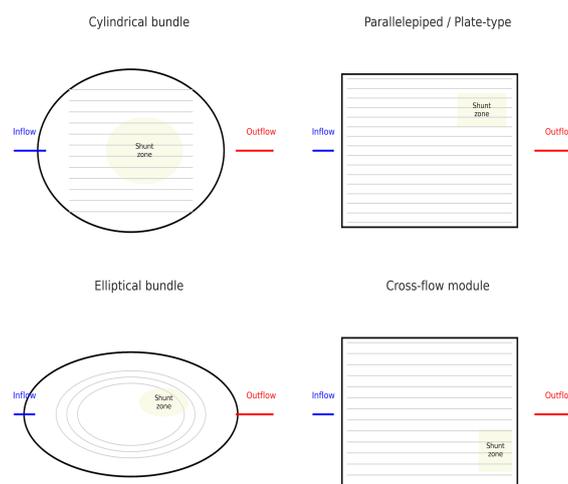


Figure 1. Schematic example representation of internal shunt and recirculation zones in hollow-fiber oxygenator geometries

For the perfusionist, it is not sufficient to observe only the pressure gradient across the integrated system or the single oxygenator. The use of **flowmeters** placed at the inlet and outlet can help quantify flow discrepancies, providing an indirect measure of shunt or recirculation. A simple and practical way to express this is:

$$S \approx 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}}$$

where Q_{in} is the blood flow entering the oxygenator and Q_{out} is the flow measured at its outlet. This formula essentially expresses the *fraction of blood that does not appear at the outlet relative to the inlet*. If inlet and outlet flows are identical, $S=0$ meaning no measurable shunt or recirculation. If the outlet flow is lower, the difference is interpreted as blood volume that either recirculates inside the device or bypasses effective membrane surfaces. Clinically, values very close to zero are considered optimal, while results above 5–10% suggest a significant degree of shunt or recirculation. In particular, analyzing shunt fraction in the context of different pump technologies may open new perspectives. With **roller pumps**, flow delivery is pulsatile or not and relatively fixed by the mechanical action of the rollers, while with **centrifugal pumps**, flow is preload- and afterload-dependent, making shunt and recirculation phenomena more dynamic and potentially more difficult to detect without careful monitoring. This technical consideration finds an intriguing physiological parallel. In the human body, shunt fractions exist both physiologically and pathologically: small intrapulmonary shunts are part of normal physiology, while atrial or ventricular septal defects are quantified by the Q_p/Q_s ratio to express pathological left-to-right or right-to-left shunting. While this analogy helps to conceptualize extracorporeal shunt phenomena, it must be acknowledged that no structured literature currently supports a direct translation of Q_p/Q_s concepts to the context of oxygenators and pumps. Nevertheless, raising this comparison may stimulate further studies on the relationship between extracorporeal propulsion technology and internal flow heterogeneity. In conclusion, the design of hollow-fiber oxygenators whether cylindrical, parallelepiped, spiral, radial, or cross-flow inevitably shapes the extent and clinical impact of shunt and recirculation. Yet equally important is the way we monitor and interpret these hidden flows, using flowmeters and pressure transducers in the setting of roller or centrifugal pumps [2,3]. Recognizing and quantifying shunt phenomena could enrich our understanding of oxygenator behavior, much as Q_p/Q_s analysis transformed our approach to congenital cardiac shunts. Opening this perspective may lead to new insights into the interaction between device design, pump technology, and perfusion practice, ultimately improving safety and efficiency in extracorporeal support.

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