available dual-lumen Avalon Elite cannula offers many advantages relative to their proposed new configuration and should be the preferred approach for patients with acute respiratory failure and for those being bridged to lung transplant. The use of the modified catheter and χ configuration of Bonacchi and colleagues¹ should be limited to patients who have no access to the currently available technology, such as the Avalon Elite dual-lumen catheter.

Enrique Diaz-Guzman, MD^{a,b}

James Lynch, MD^{a,c}

Charles W. Hoopes, MD^{a,d}

^aUniversity of Kentucky Transplant Center

Lexington, Ky

^bAssistant Professor of Medicine

Medical Director of Lung Transplant

University of Kentucky

Lexington, Ky

^cDepartment of Surgery

University of Kentucky

Lexington, Ky

^dAssociate Professor of Surgery

Director of Heart & Lung

Transplantation

Department of Surgery

University of Kentucky

Lexington, Ky

References

1. Bonacchi M, Harmelin G, Peris A, Sani G. A novel strategy to improve systemic oxygenation in venovenous extracorporeal membrane oxygenation: the " χ -configuration." *J Thorac Cardiovasc Surg.* 2011;142:1197-204.
2. Otsu T, Merz SI, Hultquist KA, Attorri RJ, Anderson HL 3rd, Scheffler DE, et al. Laboratory evaluation of a double lumen catheter for venovenous neonatal ECMO. *ASAIO Trans.* 1989;35:647-50.
3. Rais-Bahrami K, Walton DM, Sell JE, Rivera O, Mikesell GT, Short BL. Improved oxygenation with reduced recirculation during venovenous ECMO: comparison of two catheters. *Perfusion.* 2002;17:415-9.
4. Rais-Bahrami K, Rivera O, Mikesell GT, Seale WR, Sell JE, Short BL. Improved oxygenation with reduced recirculation during venovenous extracorporeal membrane oxygenation: evaluation of a test catheter. *Crit Care Med.* 1995;23:1722-5.
5. Wang D, Zhou X, Liu X, et al. Wang-Zwische double lumen cannula—toward a percutaneous and ambulatory paracorporeal artificial lung. *ASAIO J.* 2008;54(6):606-11.
6. De Bartolo C, Nigro A, Fragomeni G, Colacino FM, Wang D, Jones CC, et al. Numerical and experimental flow analysis of the Wang-Zwische double-lumen cannula. *ASAIO J.* 2011;57:318-27.
7. Bermudez CA, Rocha RV, Sappington PL, et al. Initial experience with single cannulation for venovenous extracorporeal oxygenation in adults. *Ann Thorac Surg.* 2010;90:991-5.

doi:10.1016/j.jtcvs.2011.12.058

Reply to the Editor:

Regarding the role of χ configuration at the dawning of adult bi-lumen cannula era for venovenous extracorporeal membrane oxygenation (ECMO), we read with interest the letter of Diaz-Guzman and colleagues from the University of Kentucky Transplant Center concerning our novel strategy for blood-oxygenation optimization in venovenous extracorporeal ECMO, which we call the " χ configuration." We appreciate all the useful comments received in response to the publication of our article.¹

The χ configuration strategy was born in early 2007, which was 2 years before the adult bicaval dual-lumen catheter (Avalon Elite; Avalon Laboratories, LLC, Rancho Dominguez, Calif) became clinically available (since January 15, 2009, in Europe).² The configuration was introduced to respond to some difficulties in adequate blood oxygenation with venovenous ECMO: achieving optimal oxygenation in all patients with severely impaired pulmonary functions (when high ECMO flows are needed to improve systemic oxygenation during protective ventilation to improve pulmonary recovery) and reducing the blood recirculation fraction to ensure adequate systemic oxygen delivery. The strategy was applied with a standard but customized cannula, and placement was successfully achieved with transthoracic or transesophageal echocardiographic guidance.

Since February 2009, we have used Avalon bilumen cannulas (to our knowledge, we are the first center in Europe and among the first in the world to do so). To date, we have treated more than 25 patients, with an ongoing research protocol to compare Avalon and χ configuration

performance. Indeed, the theoretic and physiologic concepts of the Avalon cannula and χ configuration basis are the same: to drain venous blood from both venae cavae and to reinfuse oxygenated blood directly through the tricuspid valve to reduce the blood recirculation fraction and to optimize blood oxygenation.

Furthermore, from our initial experience, the bilumen cannula presents various advantages that are correctly reported by Diaz-Guzman and colleagues; nevertheless, its limits and disadvantages were not presented. Intrinsically, the adult bilumen cannula presents some structural limitations and clinical restrictions.³⁻⁵ In contrast with Diaz-Guzman and colleagues, we think that an adequate and strict patient selection is necessary for appropriate use of this device to achieve optimal results.

From our initial experience we have identified some principal limitations of the adult Avalon bilumen cannula:

Maximal blood flow achieved: Also with a major dimension cannula (31 F) the limit in blood flow is 5 to 6 L/min.³⁻⁵ This value could be inadequate in different clinical scenarios, such as when pulmonary function is very impaired and patients require deep protective pulmonary ventilation.¹ In this situation, the complete extracorporeal blood oxygenation is necessary (venovenous ECMO blood flow >75% of cardiac output¹). The data in our hands seem to indicate that in these circumstances the flow generated from a 31F cannula could be insufficient, if a patient's body surface area is greater than 2.0 m² or body weight is greater than 80 kg (with our configuration, we have treated with no problems obese patients up to a body weight of 165 kg), especially if protective pulmonary ventilation is required. Similar considerations could be applied to smaller patients with hyperdynamic status (such as septic shock or fever). We have treated patients with cardiac outputs as great as 22 L/min.

Inflow and outflow pressure gradient: From our data (as yet unpublished)

and data from other investigators,^{3,5} the pressure gradients of inflow (negative pressure) and outflow (positive pressure) are for all flow regimens and cannula dimensions greater in a bilumen cannula than in the χ configuration setting. This value is critical above 4.5 to 5 L/min with the largest (31F) Avalon cannula. The clinical implications and biologic effects of elevated positive and negative pressure gradients are not clear yet; however, from our data they seem to negatively affect the coagulation system, platelet function, phlogistic system, and blood cells. Major incidences of some complication, such as hemolysis, low platelet count, and coagulation status alteration, with the Avalon Elite cannula versus the χ configuration seem to be correlated with differences in the pressures regimen.³⁻⁵

Cannula diameter: The adult bilumen Avalon Elite cannula is large and may almost completely occlude the jugular vein and the first portion of the superior vena cava. In our experience, the incidence of large thrombosis of jugular and subclavian veins is very high (nearly 80% of our patients; unpublished data).

Cannula cost: Last, but not least, the bicaval dual-lumen catheter (Avalon

Elite) is several times more expensive than the χ configuration strategy.

In conclusion, the Avalon Elite bilumen cannula does improve venovenous ECMO treatment and is the ideal device for selected patients. We believe that it is not the optimal tool in all cases, however, and actually the adult bilumen cannula seems inadequate for venovenous ECMO in a range of patients with refractory respiratory insufficiency, such as larger patients with severely impaired pulmonary function and patients with hyperdynamic status.

As an alternative, the χ configuration can be applied in nearly all cases, irrespective of corporeal dimensions, and can guarantee efficient and effective extracorporeal blood oxygenation with very low RBF and very high oxygen delivery levels, allowing protective ventilator settings when trying to achieve lung rest, avoiding overall ventilator-Induced lung injury and consequently reducing ECMO time, time to pulmonary recovery, the intensive care unit stay, adverse patient outcomes, and hospital costs.¹

Finally, we believe that the reported χ configuration strategy is an important resource for achieving optimal venovenous ECMO in different patients, that it

is associated with excellent postoperative outcomes, and that it should be part of the “ECMO armamentarium” in advanced ECMO centers to ensure the best treatment for the individual patient’s characteristics.

Massimo Bonacchi, MD

Guy Harmelin, MD

Cardiac Surgery

Medical and Surgical Critical Care

Department

University of Florence

Firenze, Italy

References

1. Bonacchi M, Harmelin G, Peris A, Sani G. A novel strategy to improve systemic oxygenation in venovenous extracorporeal membrane oxygenation: the “ χ -configuration.” *J Thorac Cardiovasc Surg*. 2011;142:1197-204.
2. Avalon Laboratories. Avalon Laboratories news. Available at: <http://avalonlabs.com/html/news.html>. Accessed December 12, 2011.
3. Bermudez CA, Rocha RV, Sappington PL, Toyoda Y, Murray HN, Boujoukos AJ. Initial experience with single cannulation for venovenous extracorporeal oxygenation in adults. *Ann Thorac Surg*. 2010;90:991-5.
4. Qiu F, Lu CK, Palanzo D, Baer LD, Myers JL, Undar A. Hemodynamic evaluation of the Avalon Elite bi-caval dual lumen cannulae. *Artif Organs*. 2011;35:1048-51.
5. Javidfar J, Brodie D, Wang D, Ibrahimiyeh AN, Yang J, Zwischenberger JB, et al. Use of bicaval dual-lumen catheter for adult venovenous extracorporeal membrane oxygenation. *Ann Thorac Surg*. 2011;91:1763-9.

doi:10.1016/j.jtcvs.2012.01.039

Notice of Correction

Re: Emmert MY, Seifert B, Wilhelm M, Grünenfelder J, Falk V, Salzberg SP. Aortic no-touch technique makes the difference in off-pump coronary artery bypass grafting. *J Thoracic Cardiovasc Surg*. 2011;142:1499-506.

In the above-mentioned article, the reported time period of the study was incorrect. The study period began in 1999 and not in 2004. The first sentence of the “Methods” section in the abstract is corrected as follows: From 1999 to 2009, 4314 patients underwent myocardial revascularization. The first sentence of the “Patients and Methods” section is corrected as follows: From 1999 to 2009, 4314 patients underwent myocardial revascularization at our institution.