to ignore the excellent surgical outcomes in terms of freedom from reintervention—albeit still with relatively short follow-up.

It is welcome to see such ambitious and successful surgical outcomes for this difficult disease, and the next step will be to understand better when to offer this type of extensive surgery over catheter intervention and whether there are

certain patient groups, patterns of disease or levels of severity of disease that are better suited to a surgical, catheter-based, or even combined approach.

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Commentary: Complex pulmonary artery reconstruction (PAR)...on a par with few others

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The manuscript by Al-khaldi and colleagues,¹ published in this edition of the *Journal*, stands on its own merits. The authors present outstanding outcomes in an extraordinarily challenging patient population. The manuscript, however, represents much more when viewed within the broader arc of the evolution of congenital heart surgery.

Patients requiring pulmonary artery reconstruction (PAR) fall into 3 main categories: arborization abnormalities (eg, major aortopulmonary collaterals); abnormal development with normal arborization (eg, elastin deficiency arteriopathy, such as Williams syndrome and similar phenotypes); and iatrogenic (eg, loss of vasculature after previous surgery or catheter-based intervention). The surgery typically addresses abnormalities at the lobar, segmental, and subsegmental the pulmonary arteries. The techniques used to address these vessels, which have evolved over the past 2-and-a-half decades, are capable of

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CENTRAL MESSAGE

Complex pulmonary artery reconstruction represents an advance thought impossible only a few years ago.

routinely producing normal or close-to-normal hemodynamics in the pulmonary circulation,²⁻⁶ an achievement thought impossible by most only a few years ago and by some even today.

Much of the advance in our field over the past 70 years has been driven by evolution of the discipline of reconstructive cardiac surgery. Increasingly complex procedures have been designed to address equally complex anomalies. As specific structural lesions were “conquered” with appropriate procedures, fewer candidates were left available, and naturally these were the most complex anomalies. The impact factor of a new procedure can be defined as the amount of positive change in quality and length of life that the introduction of the procedure imparts on the target patient population. Consider the significant impact factors for several “early” procedures, those for total anomalous pulmonary venous return, ventricular septal defect, or truncus, to name just a few. The Norwood procedure for hypoplastic left heart syndrome was developed in the 1980s, and one could argue that this was the last procedure with an

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impact factor that matched the landmark accomplishments of the early years of open-heart surgery. To be clear, advances in the field have occurred over the past 35 years, but as the maturity of the discipline has evolved, these advances have been incremental. A perusal of the presentations at our major meetings and publications in our most prestigious journals over the past 3 decades proves the point. This brings us back to PAR. The impact factors for complete unifocalization for tetralogy of Fallot with pulmonary valve atresia and major aortopulmonary collateral arteries, and for multilevel PAR for Williams syndrome and similar phenotypes, are comparable with the classic procedures developed in the early decades of the reconstructive era. Reducing systolic pulmonary artery pressure from 100 mm Hg to 25 to 35 mm Hg, as is routinely achieved in PAR,^{7,8} is *prima facie* evidence of the impact factor these procedures carry. It is likely that the PAR procedures represent the final high impact factor contribution of the reconstructive era. In future years, high impact factor procedures will come from a new discipline, the dawn of the bioengineering era.

The PAR procedures improve outcomes dramatically when compared with alternative treatment options. The ideal outcome for tetralogy of Fallot with pulmonary valve atresia and major aortopulmonary collateral arteries is a live patient with a septated heart and a right ventricular pressure less than half systemic. Early complete unifocalization can achieve this ideal outcome in more than 80% of patients.³ All other alternative approaches, both surgical and catheter-based interventional, achieve this ideal outcome in less than 25% of patients.⁹⁻¹⁴ Multilevel PAR for elastin deficiency arteriopathy reduces right ventricular systolic pressure from levels often >100 mm Hg to 28 mm Hg.¹⁵ The alternative option of catheter-based intervention achieves right ventricular systolic pressures of well over 70 mm Hg.^{16,17}

Why do these inferior alternative options persist? We don't perform Sennings and Mustards for transposition, yet the evidence for superiority of the arterial switch operation over these other techniques is not nearly as compelling as for the PAR procedures over the alternatives. One answer to the question of why inferior alternative procedures persist relates to the complexity of the PAR procedures. They are difficult to learn and challenging to perform well. Think coronary transfer in an arterial switch operation, but repeated 25 to 30 times per case, and with exposure an order of magnitude more unfavorable. The target vessels are often in a 6-inch-deep hole and obscured by pulmonary veins and bronchial structures. In addition, the 3-dimensional conceptualization required to reconstruct these vessels in a decompressed state and anticipate avoidance of compression or kinking of pulmonary veins, bronchi, or the arteries themselves, once the circulation is re-established, is nuanced and challenging.

Thus, there is concern over whether the reported results with PAR procedures are reproducible. The more far-reaching value of the manuscript by Al-khaldi and colleagues¹ is that it provides evidence that, using a programmatic approach (with all the complexities that this entails) and having a sound understanding of the fundamentals of how to technically perform PAR procedures, outstanding outcomes can be reproduced.

Risk aversion is pervasive in the current environment. This is a result of the emphasis on transparency combined with woefully inadequate risk adjustment methodology for complex procedures such as those discussed here. Transparency, in isolation, is a force for good. Inadequate risk adjustment, in isolation, is a disappointing failure. Transparency combined with inadequate risk adjustment, however, is toxic and has far-reaching implications. One of the most important is that it incentivizes the pursuit of mediocrity. Many programs will opt to avoid taking on the steep learning curve necessary to master these procedures and will perform "safer," but far less effective, surgical and catheter-based alternatives. This is unfortunate. The hope is that the outcomes demonstrated by Al-khaldi and colleagues¹ will encourage other programs to make the commitment to master these techniques.

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