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Editorial

Standardizing Imaging for Pulmonary Valve Replacement: Just What the (Interventional) Doctor Ordered

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Right ventricular outflow tract (RVOT) interventions continue to increase as more tools become available to the interventional cardiologist. Initially, the approach to treating the dysfunctional RVOT was exclusively surgical. This has expanded heavily into the interventional realm, with interventional cardiologists now able to treat a wide array of RVOTs largely because of the advent of a new generation of balloon expandable and self-expanding stent technologies. Conduit revisions/interventions (surgical or transcatheter) require thorough evaluation of proximal coronary arteries, branch pulmonary artery anatomy, degree of conduit calcification as well as the sternal relationship, which is best evaluated by cardiac computed tomography (CCT). Native outflow tracts (which previously were primarily addressed surgically) were assessed with cardiac magnetic resonance (CMR) or echocardiography because they were either regurgitant or stenotic, with criteria for intervention reviewed in detail in several guideline statements.[1-4] With the development of devices created to treat native outflow tracts, there has been a significant shift from the operating room to the catheterization laboratory for a large portion of patients. This has resulted in an explosion of patients undergoing CCT for anatomic evaluation, which is required for fit assessment. Regardless of modality of pulmonary valve replacement (PVR), the need for imaging is integral to planning.

Historically, right ventricular (RV) size and function has been a primary trigger for intervention. This was based primarily on 3-dimensional imaging using CMR, with current guidelines for PVR based on preprocedural values of RV systolic function and the RV end-diastolic volume indexed for body surface area, with a goal of normalizing the RV size and potentially function post-PVR. These were felt, at least early on, to be critical parameters both for establishing need for PVR and potential for RV recovery; however, these parameters have not been predictive of outcome or recovery. In at least 1 recent study, only age at PVR, persistently low RV function post-PVR, and the presence of atrial arrhythmias post-PVR were found to be independent predictors of outcome.[5] In another study, PVR did not confer any survival benefit regarding death, ventricular tachycardia, or both in patients after PVR.[6] Although these findings are not meant to deny the benefit of establishing pulmonary valve competency, they simply highlight that the timing and indication for intervention to achieve maximal benefit remains unknown.

Echocardiography naturally serves as the primary screening tool in the outpatient setting owing to familiarity, ease, and availability. Subsequent intermittent screening CMR studies are typically performed to correlate data and determine potential timing for intervention. Once parameters have been met (significant RV dilation, reduced function, and/or severe pulmonary regurgitation [PR]), if catheter-based intervention is going to be performed or if surgeon prefers, then the patient must undergo CCT to evaluate individual anatomy for procedural planning. There continues to be significant variability across centers regarding the level of technical expertise, equipment, and software available. This affects not only the study quality but also radiation dose administered, an area of significant concern related to the use of CCT.

In this issue of *JSCAI*, Han et al[7] provide recommendations for the performance of CCT scans in relation to optimizing the study, reducing radiation dosing as well as a standardizing the approach for reporting before planned PVR (surgical or transcatheter), providing the necessary anatomic data needed for PVR planning. This approach is based on the success in the transcatheter aortic valve replacement (TAVR) population, where protocolized imaging provides uniformity and seemingly improved procedural outcomes.[8,9] The authors also report on the ability to obtain accurate volumetric data from CCT; however, this requires good quality studies, current software packages, 64 slice or better scanners, and standardized postprocessing methods. Owing to these limitations and the concern for stochastic risks in the congenital heart population, CMR remains the standard for the assessment of RV volumes and function.

As noted in the review of indications for intervention, many of the parameters for candidacy are obtained primarily by echocardiography and symptom/functional status review, focused primarily on the presence of severe PR or pulmonary stenosis. The newer platforms of self-expanding therapies were approved by the Food and Drug Administration based on the severity of PR on echocardiogram and symptomatology. It is conceivable that the patient could proceed directly to

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volumetric computed tomography (CT) scan if echocardiography and symptom criteria are met to qualify for transcatheter PVR. For asymptomatic patients, CMR remains the reference standard[10] for deciding whether there is an indication for PVR. Improvements in the ability to obtain volumetric data from CT scan could potentially ameliorate the need for multiple 3-dimensional studies in the future; however, radiation dose continues to be of primary concern as does optimization of contrast dosing/timing, obtaining adequate fields of view, and reproducibility in measurements.

In a recent registry looking at the use of dual-source CT in patients with congenital heart disease, the age-adjusted effective radiation dose for the cohort was approximately 1 to 1.56 mSv; however, there was significant variability noted among age groups and institutions. This demonstrated that CCT can have a very low effective radiation dose in the current era in a real-world, multi-institutional cohort of patients with congenital heart disease of all ages when scanned in centers with imaging physicians experienced in congenital heart disease with access to recent-generation CT technology and dose-optimization techniques tailored to clinical indication. The variability of dose estimates between institutions indicates that there is room for further dose optimization.[11] This finding was supported by a large international registry evaluating CT radiation doses, where dose differences were found to be almost entirely associated with institutional protocols rather than patient characteristics or equipment, suggesting that dose optimization may be achieved with protocolization of scans.[12] This is consistent with the FDA-awarded efforts by the Alliance for Quality Computed Tomography working group, a part of the American Association of Physicists in Medicine, who have developed protocols and guidelines for minimizing radiation while performing technically adequate studies.[13] Post-processing is an area where significant variation exists, and standardization is likely to improve accuracy. In a meta-analysis comparing CCT with CMR assessment of RV volume and values, the agreement of end-diastolic and end-systolic volumes was better in studies with $\geq$64 CT slices; however, they too noted significant variation in how the images were postprocessed, with better agreement noted with segmentation methods similar to CMR, adding further support for the use of standardized methods.[10]

Developing best practices is mission critical to improve care delivery and can only be accomplished with interdisciplinary input from experts in their respective fields. It is crucial that patients have reliable and conscientiously performed studies to assure optimal success without adding significant risk with high radiation doses or suboptimally performed and, thus, unusable studies. These guidelines serve as an excellent springboard, providing valuable technical insights into safe and accurate performance and interpretation of CCT to guide decision making for PVR. This white paper, although an extremely helpful guide, is also thought provoking. In the future, could CCT yield adequate functional results with extremely low radiation doses? Will indications for PVR shift to echocardiogram criteria and symptomatology if RV size and function do not correlate with clinical outcomes? Is it time to rethink our imaging strategy? Further work will be required to evaluate if protocolization will achieve in PVR the same results realized in the TAVR experience. Regardless of modality of PVR, we can all agree that a multidisciplinary "heart team" approach is critical to serve this complex population in the safest and most efficient manner possible.

Declaration of competing interest

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