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Perspective

Image-Based Simulative Training for Myectomy in Hypertrophic Cardiomyopathy: An Emerging Necessity

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ABSTRACT

Surgical myectomy was initially advocated only for patients with symptoms refractory to maximal tolerated medical therapy. These were mainly symptoms of cardiac failure. In recent times, there has been a call for revision of guidelines to include patients earlier. As the disease progression cannot be reversed by most currently used drugs which become ineffective with time, this need for earlier myectomy seems mandatory. Presently, surgical expertise in myectomy is limited to specialized centers. The complexity of surgical myectomy is enhanced by the complex and variable anatomic substrate. With the need for earlier myectomy, a vast population of patients with hypertrophic cardiomyopathy will need surgery, predicating a requirement for more skilled cardiac surgeons. Mentoring programs in specialized centers may not be the solution, as is training surgeons using image-guided simulation techniques. Here, we discuss the existing simulative techniques and novel image-based preoperative planning techniques which may help guide myectomy.

Surgical myectomy is currently advocated for obstructive hypertrophic cardiomyopathy (HCM) in patients with disabling heart failure symptoms classified as New York Heart Association (NYHA) class III/IV, which has to be refractory to anti–heart failure medications, as per the American Heart Association (AHA)/American College of Cardiology (ACC)/European Society of Cardiology expert consensus guidelines.[1]

This requirement of symptoms refractory to maximal tolerated medications as a prerequisite for surgery was largely influenced by the prohibitive mortality rates of myectomy of 8% nearly 35 years ago.[2] Of late, there are several surgeons and cardiologists who feel a compelling need to revise this treatment strategy to include patients who are less symptomatic (in NYHA class II) but with symptoms significantly impacting their quality of life. The thought of calling for revision of present guidelines has resulted from observational studies demonstrating a substantial reduction in operative mortality for HCM including the apical and midventricular obstructive type from 8% to 0.4% (of nearly 95% magnitude decrease).[3]

Myectomy has shown to reverse heart failure symptoms and confer a mortality benefit.[3,4] It has also shown to decrease the incidence of sudden death and obviate the need for intracardiac device (ICD)l implantations in few anecdotal reports.[5]

Nearly 90% of patients have improvement in heart failure symptoms after myectomy, with 70% of them having no residual symptoms with resumption in normal activity (NYHA class I).[3,4] These benefits are attributable to reduction in left ventricle (LV) mass, improvements in LV cavity size, abolition of intraventricular gradients, and mitral regurgitation. There is continued beneficial ventricular remodeling that reverses the LV diastolic dysfunction without compromise to LV systolic function. Pharmacological therapy alone does not persistently control heart failure symptoms. It also does not alter the natural history of patients over time.[3]

Pharmacological therapy does not have a role in the management of the apical variant of hypertrophic cardiomyopathy.[3] Several centers revised their recommendations for earlier myectomy for patients with symptoms less than NYHA class III.[4] With benefits of early myectomy well documented in observational studies, it becomes imperative for more surgeons to be trained in myectomy.

Although there are no data defining an operator "learning curve" for myectomy,[1,6,7] the US/Canada (ACC/AHA) HCM consensus guidelines stipulate a minimum standard of 20 myectomy operations per year for a surgical team to accrue and maintain sufficient expertise.

When this is the situation in US hospitals, the situation in Europe and Asia is by far more lacking in terms of surgical expertise for myectomy. There is an acknowledged direct correlation between procedural volume (and myectomy experience) and optimal surgical outcome. This is largely due to the unique anatomic features of the LV outflow tract and the operation that is performed through an aortotomy with limited visual exposure of the field of interest, as well as the heterogeneous and variable morphology of ventricular septum, LV outflow tract, and mitral valve,[8–11] requiring preoperative and postoperative imaging and hemodynamic monitoring in the operating room.[12]

Hemodynamic monitoring in the operating room has its own pitfalls and fallacies which makes need for preoperative imaging vital. This is true even in the apical and midventricular obstructive

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types of HCM where myectomy is performed through a ventriculotomy. Despite having a larger exposure of the field of interest than in an aortotomy, myectomy requires considerable preoperative planning because damage to surrounding structures such as the mitral valve and papillary muscles can be catastrophic and counterproductive, while subminimal excision can lead to recurrence. The variable anatomic features of the septum were responsible for the suboptimal results of percutaneous alcohol ablation of the septal artery, especially factors such as a very thick interventricular septum or presence of concomitant coronary artery disease or mitral valve disease.[6]

Three-dimensional (3D) printing has shown promise in both LV outflow tract obstructive HCM and midventricular obstructive HCM.[13,14] This technology however does not lend itself to widespread use in large populations because of its cumbersome nature and several logistic constraints. Besides, thinner structures such as the mitral valve leaflets and papillary muscles do not lend themselves to 3D printing technology, making myectomy difficult because most patients with HCM have associated mitral valve abnormalities.

Simulative surgical training has shown promise in several prototypes, requiring sophisticated refinements in imaging technology.[15]

Three broad categories of surgical simulators include the simple bench model (SBM), virtual reality simulator (VRS), and human performance simulator (HPS). SBMs are “partial-task” tools that simulate a small component of a larger operation. They may be synthetic (e.g., rubber vessels to simulate coronary anastomosis) or consist of biological tissue (e.g., porcine or bovine organs to practice valve suturing). The VRS is computer-based and often lacks a physical component. Thoracoscopic or laparoscopic tools are used to manipulate virtual organs, making virtual reality simulation readily reusable with little maintenance, an advantage that can offset high initial costs. With sophisticated programming, these models can be adapted to clinical variations, interactively respond to the user, and provide performance assessment and feedback. The biggest disadvantage of this technology is the use of a two-dimensional (2D) computer screen that compromises depth perception and tactile sensation of the real 3D environment.

The HPS is a high-technology system that fuses an elaborate physical component with a computer interface. Similar to VRS, HPS can include patient variation and capabilities for assessment and feedback. However, use of biological tissue and numerous intricate parts increase resource use and maintenance time. All these tools have been confined to small sample sizes, and long-term outcome data are lacking.

The 2D interface of the VRS can be modified using a 3D image processing interface on cardiac magnetic resonance images.[16] The epicardial and endocardial borders can be traced to render a 3D image of the LV, and the location and extent of regional hypertrophy can be indicated within the LV cavity as a color map depicted on the endocardial surface, in the interest of guiding surgical myectomy. The tool can be additionally enabled to algorithmically and interactively deform the endocardial surface in user-specified locations – simulative of myectomy – in the interest of facilitating optimal surgical resection of the hypertrophic myocardium.

Virtual myectomy can be accomplished in three dimension within an interactive presurgical planning software program, using a free-form surface deformation tool applied to the endocardial surface at hypertrophic regions. This tool offers parametric control for the regional influence and magnitude of myectomy to provide the surgeon with dexterous control for virtual correction of the LV shape. Regional color maps help visualize the precise location and extent (in mm units) of the virtual myectomy on the LV endocardium, in three dimension. Although this 3D computer-based technology does not simulate surgical tools, it offers a guide for the operator regarding the magnitude and location of hypertrophy with a map of surrounding structures and the respective distances of vital structures such as papillary muscles and mitral annulus from the regions of hypertrophy (Figures:1 and 2).

The predicted postoperative LV shape can be compared against 3D LV endocardial surface reconstructions from postoperative cardiac magnetic resonance (CMR) images to validate surgical efficacy (Fig. 3).

Although overall performance in cardiac surgical procedures may improve with simulation-based training, mentoring cannot be replaced by any technological advance. There may not be a universally workable solution to this, but it remains important to derive competence in HCM surgery. It is also important that the surgical expertise gained should be passed down and perpetuate over time. While surgical expertise is well documented in centers in the US, Canada, and some centers in Europe,[4] a dire need is felt for such centers in India, making imaging options for preoperative planning and simulation imperative. Given this revision in practice guidelines for earlier myectomy, many thousands of such patients need to be identified for surgery, making the need for expertise in

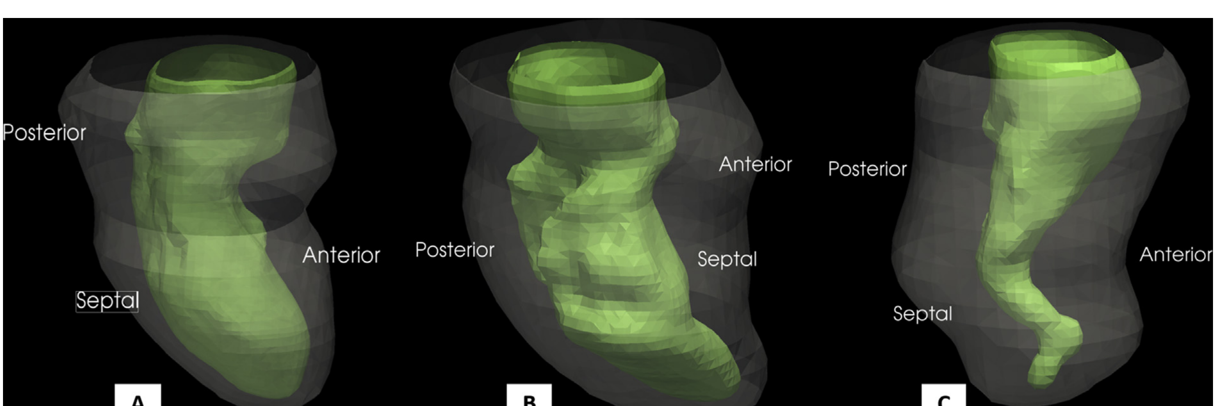

Fig. 1. End-diastolic 3D renderings of the preoperative LV endocardial surfaces (green), illustrating sites of midventricular or apical hypertrophy as dents or depressions in the surface. Midventricular hypertrophy is indicated by indentations seen on the endocardial surfaces which correspond to regionally thicker myocardial walls (i.e., space between gray epicardial and the green endocardial surface). (C) Apical hypertrophy. 3D, three-dimensional.

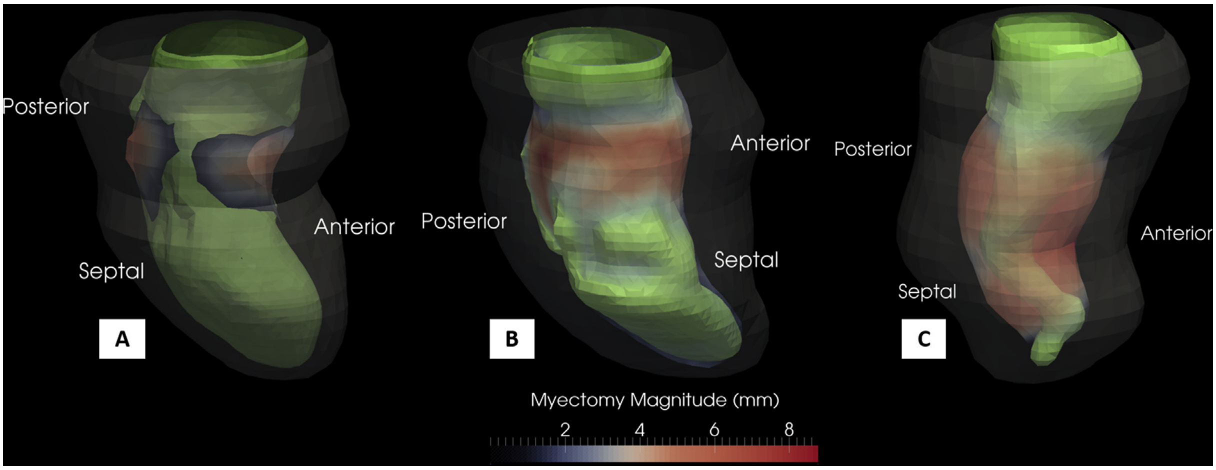

Fig. 2. End-diastolic 3D renderings of the virtual postoperative LV endocardial surfaces. Sites of virtual myectomy in the midventricular or apical regions are color-mapped from blue to red, indicative of the extent of myectomy performed, in mm units. 3D, three-dimensional.

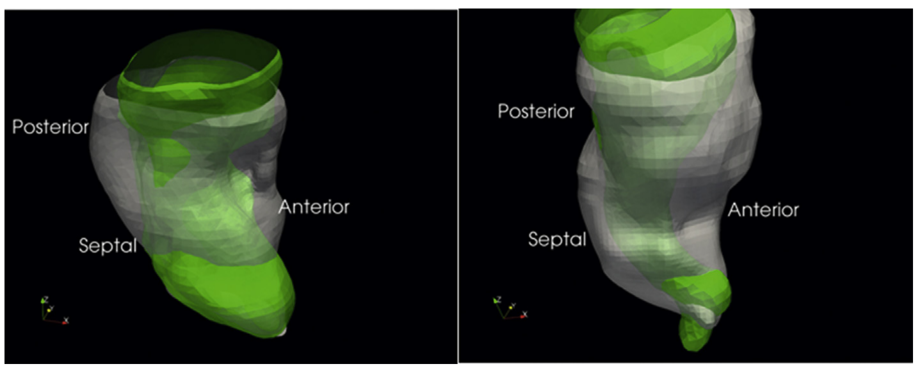

Fig. 3. End-diastolic 3D renderings of the preoperatively prepared surgical plan (rendered translucently) against the superimposed true postoperative rendering of the LV image (colored in solid green). 3D, three-dimensional.

myectomy emergent. A team approach is mandatory to achieve this goal, as are image-based tools, to aid optimal results of myectomy.

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Conflict of interest

All authors have none to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ihj.2019.03.006.

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