Aortic root numeric model: Correlation between intraoperative effective height and diastolic coaptation

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Effective height ($h_E$) is a geometric parameter that can be measured during procedures and has been suggested as a predictor of valve performance.¹ Few studies have suggested that the $h_E$ can be increased only by cusp intervention.²,³ In a previous study,⁴ we used 3-dimensional numeric models of compliant aortic valves and roots and studied the influence of aortic annulus diameter. Although we found a correlation between the $h_E$ and the coaptation height ($h_C$), we did not check the influence of the cusp size on this correlation. In this communication, we expand on our previous study and determine the correlation between $h_E$ and $h_C$ on the basis of new numeric models with different cusp sizes and our previous results.⁴

METHODS

Four new 3-dimensional aortic valve geometries, with different cusp sizes, were generated and modeled in the same manner as in our previous study.⁴ In all the new models with different cusp sizes, the root dimensions were identical and equal to the healthy case model with an aortic annulus diameter of 24 mm.⁴ The dimensions of the cusps were changed on the basis of the same geometric relationships,⁵ and their area was in the range of 86% to 116% relative to the healthy cusp. The resulting geometric heights ($h_G$), defined as the length of the cusp symmetry line, were between 15.4 and 18.9 mm. The initial geometries were generated by changing $h_G$, or the height of the commissures, while keeping other dimensions of the cusps, such as the length of the free edge. Two models were used for each of the geometries’ fully compliant fluid–structure interaction (FSI) and no-flow (“dry”) static models.⁴ A detailed description of the numeric model and its assumptions is available in our previous report.⁴ The new models were compared with the healthy model ($h_G$ = 16.2 mm), and the correlation between the $h_G$ and the average coaptation was based on all the 10 models from the present and previous studies combined.

RESULTS

Projected 2-dimensional deformed configurations of the valves, as calculated from the FSI models, are shown in Figure 1 (top row). The $h_C$ in this plane clearly increases with the increase of $h_G$. The mechanical stresses in the cusps were also calculated from the FSI models. The calculated
stress distributions in the cusps are shown in Figure 1 (second row). The case with the smallest $h_G$ was not fully closed, and, as in our previous parametric study, all the closed valves had smaller stresses. The healthy case had the lowest mechanical stress.

The $h_E$ was calculated from dry models when the applied pressure load fully closed the valve, whereas the average $h_C$ was calculated from the FSI models. The average $h_C$ is defined as the coaptation area divided by the free-edge length. Obviously, these averaged values are smaller than the maximum $h_C$ that is usually measured in echocardiography. Both the $h_E$ and the average $h_C$ increase with $h_G$. Figure 2 shows the relationship between the average $h_C$ and $h_E$ in all the 10 models of the 2 parametric studies, including the results for different aortic annulus diameters.

DISCUSSION

Large $h_C$ is considered desirable as a safety margin for preventing regurgitation, but also for reducing the mechanical stresses in the cusps. In the present study, the average $h_C$ increases with the size of the cusp, or the $h_G$. This result seems reasonable, although it is not customary to change the $h_G$ of the cusps during valve repair procedures. Nevertheless, the $h_E$ can be easily measured within the clinical setting, and both our current and previous parametric studies indicated that there is a correlation between the size of the cusp and the average $h_C$ increase. Figure 2 shows a close to linear correlation between the average $h_C$ and $h_E$. All the 3 cases with $h_E$ less than 9 mm had partially opened valves during diastole. Although these partially open valves exhibit regurgitation or leakage, they also have larger stress distribution (Figure 1), and as a result probably decreased durability. These results are in accord with the findings of Bierbach and colleagues, who found that 96% of patients with moderate or severe aortic insufficiency had $h_E$ less than 9 mm. The case with “healthy” dimensions has the best combination of coaptation and low mechanical stress.

CONCLUSIONS

These additional results strengthen our previous conclusion that improving $h_E$ during valve repair or replacement may lead to increased coaptation and better performance, especially for nonprolapsed valve geometries.

References