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LETTER TO THE EDITOR

Letter to the Editor regarding "A general three-dimensional parametric geometry of the native aortic valve and root for biomechanical modeling"

With great interest we read the article of Haj-Ali and Marom et al., presenting an extensive three-dimensional mathematical model of the aortic valve and root (Haj-Ali et al., 2012). The development of an accurate model of the aortic valve could provide insight in both the functioning of a healthy valve and several pathological processes involving the aortic valve. As the aortic valve interacts on a high level with the aortic root, the model proposed by Haj-Ali and Marom et al., which contains a model of both the aortic valve and root, seems promising.

To validate the model, the authors performed a transesophageal echocardiogram (TEE) on a patient with a healthy, tricuspid, aortic valve to measure the needed parameters and simulated the opening of the valve using this parameters implemented in the model. The results of the simulation were compared to the acquired TEE images. The authors reported a marginal error between the simulated opening position of the valve leaflets and the actual position as seen on the TEE images. Given this small error they conclude that, for the healthy valve, the model can represent reality. After the initial publication of the model in this journal, the group of Haj-Ali and Marom has published several articles using the model for simulations. In Marom et al. (2013), they report about simulations on the opening process of bicuspid aortic valves (BAVs). For all types of simulated BAVs the aortic valve area (AVA) has decreased 50% or more compared to the AVA of a tricuspid valve. Furthermore, in the case of a type 1 BAV in which two of the cusps are fused (according to the classification of Sievers and Schmidtke (2007)), the fused leaflets do not open at all. Though this may be true in most patients in clinic, the BAV is not stenotic by essence. Some BAVs open normal and therefore are not probable to result in any discomfort. Due to this, these valves are rare to see in the clinic. Nevertheless, this hypothesis is emphasised in a study conducted by Cognet et al. (2013) on 70 children with a BAV. In this study, 45 BAVs were non-stenotic (mean AVA 1.99 cm^2/m^2). The remaining 25 subjects had a stenotic BAV (mean AVA 1.51 cm^2/m^2). Moreover, in the group of the stenotic BAVs, the mean peak gradient was 30 mmHg, indicating the presence of mild to moderate stenosis. A study of Michelena et al. (2008) with a follow-up of 20 years focussing on asymptomatic BAVs also shows the progression but initial absence of stenosis in patients diagnosed with BAV. In our opinion, this proves stenosis is not a key-feature of the BAV but may be the results of an ongoing process (secondary to the BAV) taking years to develop.

We have to mention that Haj-Ali and Marom et al. are not the only group presenting this result. Jermihov et al. (2011) is an article in which the simulation of BAVs also results in restricted opening of the valves.

The simulation might result in no opening of the fused leaflets when the leaflets are modelled with substantial higher stiffness compared to the leaflets in the tricuspid valve. Even so, such increased stiffness is not mentioned in Marom et al. (2013). So, we think that the cause of the unrealistic opening of the BAV lies in the mathematical model. After comprehensive discussions, we concluded that the absence of redundant leaflet tissue in the model might cause the reduced opening. Redundant tissue is present in many congenital BAVs (Edwards, 1961). It has been described in literature that BAVs containing redundant leaflet tissue tend to develop valvular insufficiency (e.g. due to prolapse) whereas BAVs with no redundant tissue tend to develop stenosis (Braverman et al., 2005). In our opinion, the redundant tissue ensures the ability of the fused leaflets of the BAV to open. In the article of Haj-Ali and Marom et al., this redundant tissue is not modelled. Because of this, the fused leaflet is unable to open. We suggest that a realistic general model of the aortic valve and its pathological presentations (such as a BAV) is able to include the presence of redundant tissue.

In order to be more realistic, we want to note another possibility for the initial normal opening of BAVs. That is, the extent of the fusion. If the fusion of the leaflets is not complete, the fused leaflet is less restricted in its movement. Nevertheless, this does not explain why type 0 BAVs with no fused leaflets also open normal. Thus, we discarded this scenario.

Concluding, the model presented by Haj-Ali and Marom et al. is a good representation of the tricuspid aortic valve. Simulating BAVs using the model results in severe limited opening of the leaflets. However, in reality, such limited opening is initially not present in most BAVs. Therefore, the model is not suitable for modelling BAVs. Using this model to provide insight in the BAV could lead to incorrect results.

Conflict of interest statement

All authors declare to have no conflicts of interest regarding the content of this letter.

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Authors' reply regarding "A general three dimensional parametric geometry of the native aortic valve and root for biomechanical modeling"

We appreciate the comments of Fabius et al. (2013) regarding our general parametric geometric model of native aortic valves (AVs) (Haj-Ali et al., 2012). In their letter, concerns were raised that the use of our geometric model of tricuspid aortic valves (TAVs) might not be suitable when applied for bicuspid valves (BAVs) since it may predict a stenotic configuration. We are glad that Fabius et al. (2013) note that our geometric model is a "good representation" of non-pathologic TAVs, as was the original aim of our proposed mathematical equations. However, the BAV geometry with the fused cusps (Marom et al., 2013), the main concern of the above letter, was actually calculated from a finite element analysis rather than from our TAV geometric model. In the BAV biomechanical analysis of Marom et al. (2013), two of the "TAV" cusps were fused together by moving them into each other to generate the BAV geometry. Fabius et al. (2013) correctly mentioned that in our recent BAV study there is no redundant cusp tissue. Therefore, the motion of the cusp may have been restricted. This representation of BAV geometry is indeed different from our general parametric geometry of TAVs, but it is similar to other previous numerical models (Conti et al., 2010; Jermihov et al., 2011). That is why our calculated opening areas for BAVs were comparable with these previous BAV studies.

In summary, our parametric TAV geometry was validated only against three dimensional transesophageal echocardiogram of non-pathologic TAV. We agree with Fabius et al. (2013) suggestion for the need to model BAV specific representation and capture its non-stenotic behavior. Our TAV geometric representation can be extended to include the redundant cusps′ tissue in BAVs and thus generate biomechanical models that can be validated against scans of non-stenotic BAVs.

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