### **INVITED COMMENTARY**

# Image-based machine learning supporting surgical mitral annuloplasty ring sizing-a four-dimensional perspective

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Since the first introduction by Carpentier [1] in 1983, a multitude of annuloplasty rings made by different manufacturers has entered the market and is used in almost every surgical mitral repair procedure to restore a sufficient amount of leaflet coaptation and/or to provide a durable repair. Annuloplasty rings are available in different sizes and the selection of the appropriate ring size is considered critical. On the small side of the spectrum, a ring may result in functional mitral stenosis [2] or increase the risk of systolic anterior mitral leaflet motion or ring dehiscence [3]. On the large side of the spectrum, the amount of leaflet coaptation may not be sufficient, potentially resulting in either residual or recurrent mitral regurgitation [4]. Since the procedure of ring size determination currently relies highly on the surgeon's expertise, quantitative models including machine learning-based models may be useful. In their manuscript, the authors used three-dimensional echocardiographic mitral valve reconstruction models to support the surgical decision process of determining the correct annuloplasty ring size [5]. We explore the group's innovative approach from 4 different perspectives.

## SURGICAL PERSPECTIVE

Nowadays, determining the correct annuloplasty ring size is usually done intraoperatively using sizers provided by the manufacturer. The procedure relies more on surgical experience rather than a scientific rationale [6]. The reasons for the lack of a sound scientific rationale are diverse. First, dimensions of commercially available rings are often proprietary. Each ring type has an individual sizer, but neither sizer dimensions nor if or how sizer dimensions relate to annuloplasty ring dimensions are provided by the manufacturer. Second, reconstruction strategies may vary highly (e.g. 'leaflet respect vs resect approaches') and may directly affect the size of the selected annuloplasty ring. Lastly, the anatomic dimensions that are suggested by the manufacturers as a reference for the sizer may vary (e.g. sizing from trigone to trigone, commissure to commissure, anterior mitral leaflet area) and may not be easy to reproduce, resulting more in an 'eyeballing' approach than a sound and reproducible scientific procedure. Despite these aspects, the outcomes reported after surgical mitral valve repair are excellent [7]. Senior surgeons may therefore consider efforts to improve the sizing procedure unnecessarily. It should, however, be noted that outcomes reported in the literature usually come from highly experienced surgeons and may only address certain valve pathologies. Consequently, their results may not apply to surgeons with less experience, or to patients with more complex pathologies [8]. Furthermore, conventional sizing strategies using ring sizers can become more difficult when taking less-invasive approaches (e.g. fully endoscopic or robotic access) where the exposure of anatomical reference points for ring sizing may become increasingly difficult. Determining the appropriate annuloplasty ring size preoperatively in such cases may be particularly helpful. From a surgical perspective, approaches enabling us to objectively and reproducibly determine the ring size preoperatively are desirable to shorten surgical learning curves, prevent the selection of inappropriate ring sizes, decrease conversion rates of mitral repair to replacement, facilitate minimally invasive procedures and improve outcomes after mitral repair.

## **ENGINEERING PERSPECTIVE**

Machine learning approaches based on cardiac imaging have not yet been translated into routine clinical practice. In the present work, the authors take an important step towards changing the current paradigm. To this end, they apply a regression model to essentially 'learn' their practice's decision-making process. In other words, the model captures their expertise and makes it available—through their regression analysis—to other surgeons with potentially less experience. However, an inherent limitation of this approach is that the outcomes are limited to their practices' best outcomes, which may not be globally optimal, e.g. due to patient heterogeneities, the use of other repair strategies, or

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differences in annuloplasty ring types. I envision that future steps will overcome the aforementioned limitation by combining noninvasive imaging with high-fidelity patient-specific models. For example, numerical models using the finite element method have shown great promise in predicting the impact of mitral valve repairs [9, 10]. Such preclinical tools could then be used to select the best ring size and type from thousands of possible combinations to optimize both traditional measures of surgical success as well as non-traditional measures. For example, in addition to optimizing coaptation competence, they could also be used to minimize leaflet stress by lowering the risk of ring dehiscence and adverse, maladaptive remodelling [11]. This vision is moving within our reach as valve models gain in fidelity, and image-processing and simulation tools keep getting faster [11, 12]. From an engineering perspective, the methodology described by the authors represents a significant step on a challenging and exciting journey towards fully-automatic preoperative ring sizing.

# **CARDIOLOGICAL PERSPECTIVE**

Four-dimensional (4D) imaging has become the preoperative imaging standard before mitral valve surgery, and most major vendors of advanced echocardiography machines now offer some sort of semi-automated analysis tool for the mitral valve, similar to that used by the authors. While earlier quantitative 4Dechocardiography often required extensive post-processing and was technically challenging, advances in TEE-probe technology and the computing power of ultrasound machines have accelerated such analyses considerably and made them technically feasible for clinical routine use. The authors of the present study report an additional time investment for post-processing of  $\sim$ 15 min per patient, which corresponds closely with our clinical experience for an experienced imager. As most vendors now integrate machine learning-based image recognition and automated measurements in their software packages, this time will likely become even shorter in the near future. From a cardiological perspective, preoperative ring sizing using echocardiography and image-based machine learning tools appears technically feasible but increases the duration of the examination.

### **ECONOMIC PERSPECTIVE**

Machine learning-based software tools are not cheap and must be purchased as individual upgrades. Given the excellent outcomes reported after surgical mitral valve repair, a novel methodology raising time and costs for a patient's hospital stay appears unattractive. Provided, however, that the approach can be translated to any centre performing mitral repair and is even automatically doable, additional aspects may be considered. Machine learning tools that accelerate and facilitate decision processes in the operating room will consequently save time, raise surgical quality and potentially shorten the postoperative length of stay. Such potential advantages could—as my surgical colleague states above—apply both to less-experienced surgeons or centres handling lowercase numbers and to experienced surgeons aiming to perform the procedure less invasively. From an economic perspective, it therefore makes sense to suggest that image-based machine learning could ultimately provide a financial benefit by: (i) saving operating time and reducing postoperative length of stay; (ii) lowering costs by preventing the selection of inappropriate ring sizes; (iii) reducing the number of reoperations; and (iv) increasing the number of admitted patients by improving outcomes.

## CONCLUSION

From a 4D perspective, surgical mitral annuloplasty ring size selection supported by image-based machine learning is potentially an important tool in the planning and execution of mitral valve repair. Approaches that can be translated to any surgical centre and that are entirely automated are desirable. Future steps may combine non-invasive imaging with high-fidelity patient-specific models. Ultimately, such approaches have the potential to improve patient outcomes further, increase repair rates, make the procedure less invasive and more cost-effective and raise the number of patients admitted for surgical mitral valve repair.

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