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Evaldas Girdauskas, MD, PhD, Theresa Holst, MD, Sina Stock, MD, Thomas Kröncke, MD, PhD, Maria von Stumm, MD, Josua A. Decker, MD

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Biomechanics of aortic valve annuloplasty: same goal, different techniques

Evaldas Girdauskas[1], MD, PhD, Theresa Holst[1], MD, Sina Stock[1], MD, Thomas Kröncke[2], MD, PhD, Maria von Stumm[3, 4*], MD, Josua A. Decker[2*], MD

1- Department of Cardiothoracic Surgery, University Hospital Augsburg, Augsburg, Germany

2- Department of Diagnostic and Interventional Radiology, University Hospital Augsburg, Augsburg, Germany

3- Department of Congenital and Pediatric Cardiac Surgery, German Heart Center Munich, Technische Universität München, Munich Germany

4 – Division of Congenital and Pediatric Heart Surgery, University Hospital Munich, Ludwids-Maximilians-University, Munich Germany.

* both authors contributed equally

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Corresponding author:

Evaldas Girdauskas MD, PhD

Department of Cardiothoracic Surgery, Augsburg University Hospital

Stenglinstr. 2, 86156 Augsburg, Germany

e-mail: evaldas.girdauskas@uk-augsburg.de

Central message: different annuloplasty techniques in bicuspid aortic valve repair exert specific biomechanical forces on aortic annulus components and have therefore different impact on geometric annulus remodeling.

Central Picture: biomechanical effects of three different aortic valve annuloplasty approaches

Abbreviations:

Aortic regurgitation (AR)

Aortic valve (AV)

Bicuspid aortic valve (BAV)

Regional longitudinal strain (RLS)

Aortic valve (AV) repair has become an established technique in the non-elderly adults presenting with an aortic regurgitation, as demonstrated by very satisfactory periprocedural and 1-year cardiac event-free survival in the multicenter GARY registry (1). Furthermore, AV repair was associated with a significantly better 1-year survival and 1-year cardiac event-free survival compared with surgical aortic valve replacement in propensity score weighted analysis of the patients with an aortic regurgitation (2). Therefore, a broader adoption of AV repair techniques, in particular in young patients with a congenital bicuspid aortic valve (BAV) disease seems to be highly warranted.

Annuloplasty is a crucial component of BAV repair with significant implications on the durability of the repair (3). Various annuloplasty techniques have been proposed over the last decades; all of them strive for the same goal of aortic annulus remodeling and stabilization. However, biomechanical principles and dynamic effects of annuloplasty techniques on the aortic annulus have been only rudimentary addressed. Quite a number of monocentric studies comparing the outcomes of different AV annuloplasty concepts has been previously published (4,5), however, no multicenter and prospective comparative randomized trial on this topic is yet available. Understanding the biomechanical implications of specific annuloplasty method is crucial to identifying technical shortcomings and limitations.

From a pathophysiological point of view, active remodeling of the rigid muscular aortic valve annulus (6) and the restoration of a symmetric post-repair BAV configuration (7) are the key components of a durable BAV annuloplasty. In ***Figure 1***, we highlight the biomechanical aspects of three established BAV annuloplasty approaches. Specific focus was on the effects of different annuloplasty techniques on the geometric shape of the annulus, in relation to the symmetry of commissural orientation.

As demonstrated in ***Figure 1a***, the aortic annulus consists of two fundamentally different anatomic components: (a) a flexible and unsupported fibrous aortic annulus, which extends from the right - non-coronary commissure to the left fibrous trigone, and (b) a rigid and firmly embedded muscular aortic annulus, largely covered by the right ventricular outflow tract (yellow marking). There is some supportive data on the different biomechanical features of the muscular vs. fibrous AV annulus. Our preliminary segmental AV annulus analysis by means of regional longitudinal strain (RLS) revealed significantly decreased RLS in the muscular part of AV annulus in aortic regurgitation (AR) patients vs. healthy controls, while RLS values were comparable in the fibrous component of AV annulus (8). Furthermore, Benhassen et al. used sonomicrometry cristals for the evaluation of segmental AV annulus dynamics during the cardiac cycle, and convincingly showed significant differences in the segmental annulus deformation between the right coronary vs. the non-coronary sinus (9).

Based on our previous clinical observations (10) and some supportive data from the literature (6), we argue that both aortic annular components behave differently in our attempts to reduce and remodel the annulus diameter. The muscular aortic annulus, in particular in the area between the left and right coronary commissure and the mid-part of the right coronary sinus, is deeply anchored in the interventricular muscular septum and, therefore, is much less amenable to geometric reshaping maneuvers. In line with this statement, an experimental study by Benhassen et al. revealed significant differences in the AV annulus dynamics after external Dacron prosthesis annuloplasty vs. PTFE suture annuloplasty (6).

The majority of BAVs are congenitally asymmetric, i.e., type B or C BAV morphotype (previously type I Sievers) (11) and present in the form of right and left coronary cusp fusion (***Figure 1a***). In such cases, the proportion of the muscular aortic annulus outweighs substantially the fibrous annular component, and therefore, extensive geometric reshaping of the muscular aortic annulus is needed to obtain a symmetric post-repair BAV configuration.

Taking these considerations into account, an aortic annulus reduction with a *circular suture annuloplasty* (***Figure 1b***) acts predominantly on the area of the lowest tissue resistance, i.e., in the part of the unsupported fibrous aortic annulus component. The main force vectors are directed towards the muscular interventricular septum; i.e. the PTFE suture pulls the fibrous component of the aortic annulus towards the muscular septum. The reshaping of the muscular aortic annulus is incomplete and the asymmetrical BAV configuration persists after the suture annuloplasty resulting in markedly restricted fused cusp mobility and increased transvalvular gradients (see **Table 1**). Previous data indicate significant number of recurrent AR and redo surgery cases after PTFE suture annuloplasty (10).

External prosthesis annuloplasty (i.e., Dacron graft, Teflon strip) aims to circularly reduce aortic annulus diameter and entails several fixation points in the fibrous and muscular annular components (***Figure 1c***). The force vectors act more homogeneously on the aortic annulus, as compared to the suture annuloplasty. However, active geometric reshaping of the muscular annulus is also limited by the heterogeneous aortic annular tissue characteristics, in particular in the mid-part of the right coronary sinus. In other words, annular reduction occurs predominantly in the regions of lower annular tissue resistance (i.e., fibrous component). Furthermore, the asymmetrical annular shape in type C BAV is not sufficiently corrected by external prosthesis annuloplasty, resulting in persisting asymmetry after AV repair (***Figure 1c***). As a consequence, the mobility of the fused cusp is frequently limited and transvalvular gradients increased after external prosthesis annuloplasty (see **Table 1**).

Internal ring annuloplasty with orientation of commissural posts at 180 degrees (e.g., HAART 200 device) (***Figure 1d***) enables selective reshaping of both annular components by forcing them into a strictly symmetric configuration. An active adjustment of both annular components to the internal device shape occurs, causing an extensive reduction of the muscular annular portion. The intraoperative sizing for internal ring annuloplasty using HAART 200 device is based on the geometric orientation and size of the non-fused cusp. Specific ball sizer is used for the measurement of the non-fused cusp to assess the commissural orientation and, in particular, surface area of the non-fused cusp. This sizing maneuver generally provides the values of 23mm or 25mm; all remaining numbers are unusual. The fused cusp and the muscular component of the AV annulus respectively, is actively adjusted to the size as the non-fused (i.e., fibrous part of the annulus) during the internal ring implantation, resulting in a symmetric geometric shape of repaired BAV. In other words, the size of the non-fused cusp (i.e., length of the fibrous AV annulus) defines the post-repair length of the muscular annulus which is required to obtain a completely symmetric BAV configuration. Consequently, a completely symmetric post-repair BAV shape is restored, allowing for better fused cusp mobility and lower transvalvular gradients (see Table 1) (7).

Considering the biomechanical differences, we advocate prospective comparative outcome studies among different annuloplasty approaches.

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Table 1. *Impact of the annuloplasty technique on functional result after repair of severely asymmetric bicuspid aortic valve (type C BAV).*

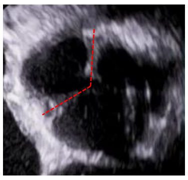
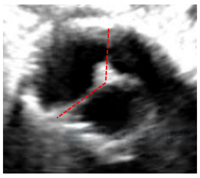
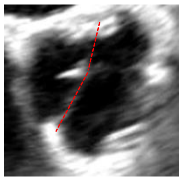
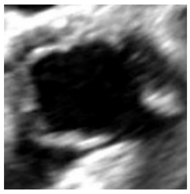
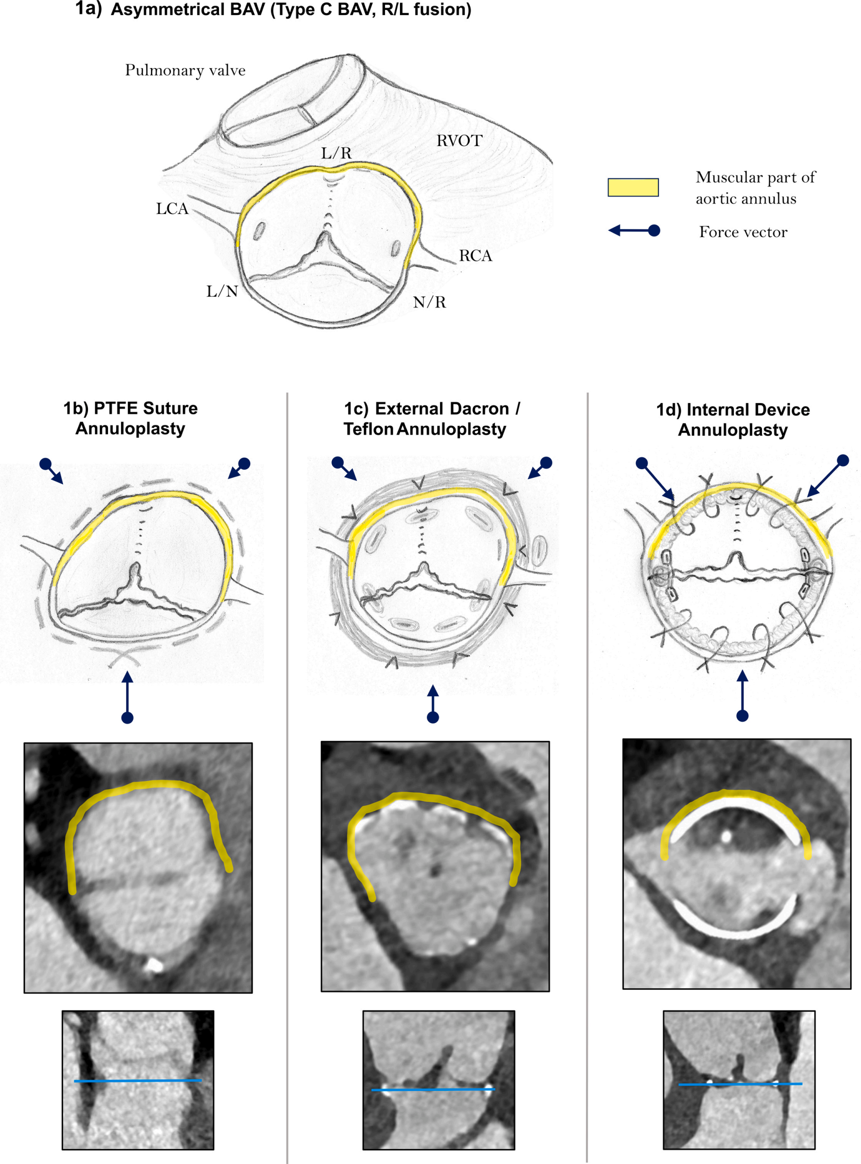
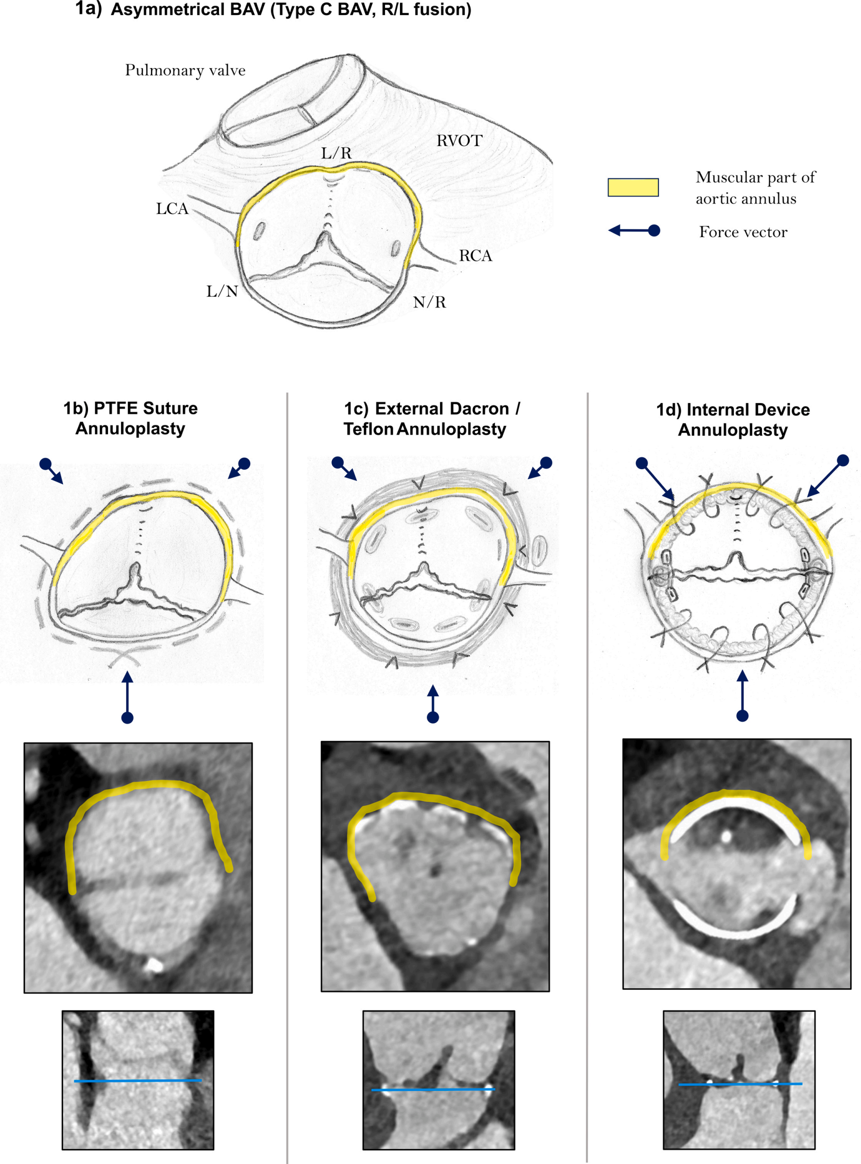
Annuloplasty	PTFE suture	External prosthesis	Internal ring
Commissural orientation after repair	 very asymmetric (type C)	 asymmetric (type B)	 symmetric (type A)
Systolic opening of the fused cusp	 restricted	 restricted	 normal
Systolic transvalvular gradients	Increased (dpmean > 15mmHg)	Increased (dpmean 10-15mmHg)	Normal (dpmean < 10mmHg)

Figure Legends

Figure 1. Biomechanical effects of three different aortic valve annuloplasty approaches. A) Asymmetrical BAV (Type C BAV, R/L fusion) B) PTFE suture annuloplasty C) External Dacron/Teflon annuloplasty D) Internal device annuloplasty.


1a) Asymmetrical BAV (Type C BAV, R/L fusion)
Pulmonary valve
RVOT
L/R
LCA
RCA
L/N
N/R
Muscular part of aortic annulus
Force vector
1b) PTFE Suture Annuloplasty
1c) External Dacron / Teflon Annuloplasty
1d) Internal Device Annuloplasty


1a) Asymmetrical BAV (Type C BAV, R/L fusion)
Pulmonary valve
RVOT
L/R
LCA
RCA
L/N
N/R
Muscular part of aortic annulus
Force vector
1b) PTFE Suture Annuloplasty
1c) External Dacron / Teflon Annuloplasty
1d) Internal Device Annuloplasty