Balloon sizing in surgical ventricular restoration: What volume are we targeting?

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Surgical ventricular restoration (SVR) by endoventricular circular patch plasty was described by Dor and colleagues[1] as a new approach to treat patients with left ventricular (LV) aneurysm. Over time, this technique was optimized, and most centers currently use an intraventricular balloon to standardize volume and shape of the residual cavity. During SVR, the left ventricle is opened through the infarct, and an endocardial encircling suture (Fontan stitch) is placed at the transitional zone between scarred and normal tissue. Next, the balloon is introduced into the left ventricle and filled with 50 to 60 mL saline per square meter of body-surface area. The Fontan stitch is tightened to approximate the ventricular wall to the balloon, and the residual orifice is closed with a patch. Subsequently, the excluded scar tissue is closed over the patch to ensure hemostasis. The guiding principle behind this operation is the concept that SVR reduces wall stress (according to Laplace's law) leading to reduced oxygen demand and improved function of the healthy remote myocardium. The balloon technique is generally considered to produce more consistent and more predictable results with improved clinical outcome.[2]

One of the first papers to describe balloon sizing mentioned that the balloon was inflated to check that the new LV diastolic volume was between 50 and 70 mL/m^2.[3] Recently, Dor and associates[2] reported a tighter range of 50 to 60 mL/m^2 and explained that the balloon should help to avoid excessive volume reduction, which might cause impaired diastolic function and restrictive cardiomyopathy. The technique is referred to as ''diastolic volume balloon sizing,'' but the basis for selecting this specific target volume range was not explicitly mentioned. To put the values in perspective, recent magnetic resonance imaging studies indicate a normal end-diastolic volume index (EDVI) of 74 $\pm$ 15 mL/m^2 in men and 65 $\pm$ 11 mL/m^2 in women with, respectively, 25 $\pm$ 9 mL/m^2 and 18 $\pm$ 5 mL/m^2 for indexed end-systolic volume (ESVI).[4] Furthermore, a 20% increase in EDVI after myocardial infarction is considered to indicate remodeling,[5] and an ESVI > 60 mL/m^2 is associated with advanced heart failure.[6] Thus, if one assumes that balloon volume predicts post-surgery end-diastolic volume (EDV), even balloon inflation to 60 mL/m^2 would seem too small. However, a direct correspondence with the resulting in vivo EDV may not be expected. First, the compliance of the arrested heart during surgery will differ from the compliance of the beating heart after surgery. Second, even if they were the same, the EDV of the beating heart strongly depends on filling pressure, and it is unclear how much the arrested heart is preloaded when the surgeon tightens the Fontan stitch.

CLINICAL SUMMARY

To investigate this issue, we compiled post-SVR LV volumes from studies that used balloon sizing (Table 1). We focused on studies reporting values obtained within the first year after SVR to limit possible confounding effects of late remodeling.[2,7-12] Two large-scale studies, RESTORE[13] and STICH,[14] were not included in Table 1 because it was not clear whether a balloon was consistently used in all participating centers. However, post-SVR ESVI was 57 $\pm$ 34 mL/m^2 in RESTORE and 67 mL/m^2 in STICH. Interestingly, post-SVR EDVI and ESVI were relatively similar between studies, suggesting that the balloon helps to standardize results. Furthermore, overall mean EDVI was 84 $\pm$ 25 mL/m^2 and mean ESVI was 52 $\pm$ 21 mL/m^2, indicating that end-systolic volume (ESV) rather than EDV corresponded with the volume of the balloon.

DISCUSSION

Our results put into question the use of the term ''*diastolic* volume sizing.'' This finding may indicate that the stiffness of the arrested heart is higher than the diastolic stiffness of the beating heart. An alternative explanation could be that when the left ventricle is closed over the balloon, this is done with very limited stretching of the muscle and thus represents a relaxed but unloaded condition, in which case the volume may be close to the in vivo ESV.[15] However, the correspondence could be fully coincidental, and a quantitative relationship between balloon volume and post-SVR ventricular volume (either EDV or ESV) can only be reliably determined from studies with multiple balloon sizes, which currently are not available. Although it seems plausible that using a larger balloon would result in a larger post-SVR EDVI and ESVI, this effect has not yet been established.

Apart from the possible advantage of more standardized results, a common concern with SVR is the potential risk of creating diastolic dysfunction, and it is likely that the balloon method may help to avoid creating too small LV

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TABLE 1. LV volumes pre- and post-SVR

				Pre-SVR		Post-SVR	
First author (year) and reference	Patients (n)	Follow-up	Imaging	EDVI (mL/m^2)	ESVI (mL/m^2)	EDVI (mL/m^2)	ESVI (mL/m^2)
Bové (2009)[7]	23	12 mo	Echocardiography	107 ± 23	77 ± 17	61 ± 9	39 ± 5
Dor (2008)[2]	104	1 mo	MRI	125 ± 37	93 ± 29	83 ± 23	51 ± 18
Castelvecchio (2008)[8]	146	At discharge	Echocardiography*	110 ± 35	77 ± 33	79 ± 16	47 ± 14
Dardas (2008)[9]	15	12 mo	Echocardiography*	113 ± 24	90 ± 29	73 ± 25	46 ± 21
Menicanti (2007)[11]	301	7–10 d	Echocardiography*	129 ± 40	95 ± 34	85 ± 29	55 ± 23
Tulner (2006)[12]	21	6 mo	Echocardiography*	136 ± 43	102 ± 42	84 ± 27	55 ± 27
Di Donato (2004)[10]	30	10 d	Angiography	202 ± 76	144 ± 69	122 ± 48	69 ± 40

LV, Left ventricle; *SVR,* surgical ventricular restoration; *EDVI,* end-diastolic volume index; *ESVI,* end-systolic volume index; *MRI,* magnetic resonance imaging. *Reported absolute LV volumes were indexed using an average value for body surface area: 1.82 m^2.[4]

chambers. However, whether the balloon method can be effectively used to target a specific post-SVR LV volume and, subsequently, whether adapting post-SVR LV volume actually helps to improve outcome need to be established in future studies.

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