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Intra-aortic balloon pump: Looking at the other side

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Abstract

Intra-aortic balloon pump has been the most commonly employed cardiac assist device in the past, although, in recent years, its use in cardiogenic shock has been questioned. The pathophysiology of the proximal part of the balloon has been well studied, whereas, hemodynamics and flow below the distal portion of the balloon have not been fully understood yet. The distal flow contains a three-wave flow pattern during diastolic balloon expansion: a flow reduction in early diastole, a backflow in mid-diastole followed by a tele-diastolic flow. More research on this topic is warranted to better understand the physics of the distal part of the balloon and its interaction with the three components of the local regulatory system: intrinsic (local metabolic and myogenic), extrinsic (autonomic nervous system), and humoral (local or circulating vasoactive substances). These new insights will be a guide for new balloon designs that will allow enhanced performance and improved outcomes.

KEYWORDS
abdominal flow, circulation, intra-aortic balloon

INTRODUCTION

Intra-aortic balloon pump (IABP) has been for decades our trustworthy companion in supporting cardiac patients.[1] For decades IABP has been the most employed temporary cardiac assist device worldwide.[1] Although its popularity has been recently overshadowed,[2] the IABP is still the primary choice during several cardiac interventions, performing very well even in very complicated clinical situations.[3] The pathophysiology of the proximal part of the balloon has been well studied, whereas, below the distal portion of the balloon, it has been investigated[4,5] but it has not been fully understood yet.[6] Research toward the pathophysiologic changes that occur at the distal part of the balloon can provide insights into the influence of balloon-related factors over visceral ischemia.

1 | BOWEL ISCHEMIA

Despite the improved design of balloon catheters and implantation techniques over the years, visceral ischemia is still a challenging and insidious complication, resulting in irreversible organ damage and unfavorable prognosis.[5] Malpositioning of the balloon is one of the causes of visceral ischemia.[7] Indeed, optimal hemodynamic support during IABP counterpulsation is highly reliant on the correct positioning of the balloon, proximally, 1 to 2 cm below the left subclavian artery origin.[7] However, although malpositioning is the leading cause of visceral ischemia, other causes include migration of the balloon or anatomic-to-balloon length mismatch resulting in visceral side branch obstruction.[8] Nonetheless, even when correctly positioned and when its size has been appropriately selected, intestinal

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and renal ischemia may occur, and, under these circumstances, the causes of bowel ischemia are widely unknown.[9]

2 | THE PROXIMAL END

The inflation and deflation of the balloon generates compression and expansion during IABP assistance generating two pairs of forward and backward waves, the intensity of which and their hemodynamic effects in the aortic root have been described in terms of the wave propagation.[10-12] It has been shown that the compression's energy is positively related to augmentation, whereas depression energy is related to the end-diastolic pressure.[11] As a consequence, the systolic aortic pressure is reduced during balloon deflation as a result of the induced reduction of left ventricular afterload. Peak systolic aortic pressure usually decreases during IABP as well as mean systolic pressure, leading to an additional decrease in left ventricular systolic work.[13] Cardiac output and stroke volume rise due to either an improvement of left ventricular pumping performance during assistance or to the pumping efficiency of the intra-aortic balloon itself. Left ventricular end-diastolic pressure and volume may decline depending upon the contractility of myocardium and the severity of heart failure.[9] These changes occur independently of changes in coronary flow,[8] and it has been shown that the effects of IABP in stable patients with severe coronary artery disease are mainly due to a reduction in demand, rather than to a primary increase in coronary blood flow.[14]

3 | WHAT HAPPENS DISTALLY?

The distal flow contains a three-wave flow pattern during diastolic balloon expansion (Figure 1).[15] First, there is a flow reduction in early diastole, attributable to an increase in local receptor-mediated vascular resistance (secondary to the early diastolic pressure increase and the stretch in the arterial wall). This phase is followed by the backflow in mid-diastole, due to the "vacuum" mechanism during early balloon deflation at the end of mid-diastole. Finally, there is a tele-diastolic flow re-increase related to aortic elasticity, aortic energy storage, and potential energy converted back to kinetic energy by the elastic recoil of the wall.[15] Interestingly, the use of a shorter and larger cylindrical balloon improves but does not solve the mesenteric hypoperfusion.[16] Indeed, while it performs better in mid-diastole, avoiding reversed flow, and in tele-diastole, leading to a higher flow increase, it shows a flow reduction at early systole comparable to the standard-size balloon.

The absence of "negative flow" at mid-diastole might be related to the balloon dimension (shorter but with larger diameter), producing a "vacuum" force that is not strong enough to overcome the forward blood flow in the mesenteric artery. At the same time, the higher end-diastolic flow increase might be due to higher aortic elasticity, and therefore, higher energy storage as a consequence of the low encumbrance of the small balloon. Hence, while the short design may help to improve visceral flow during deflation restoring the normal flow at the end of diastole, it does not seem to be of any help in reducing the dramatic drop occurring at the beginning of diastole that is presumably

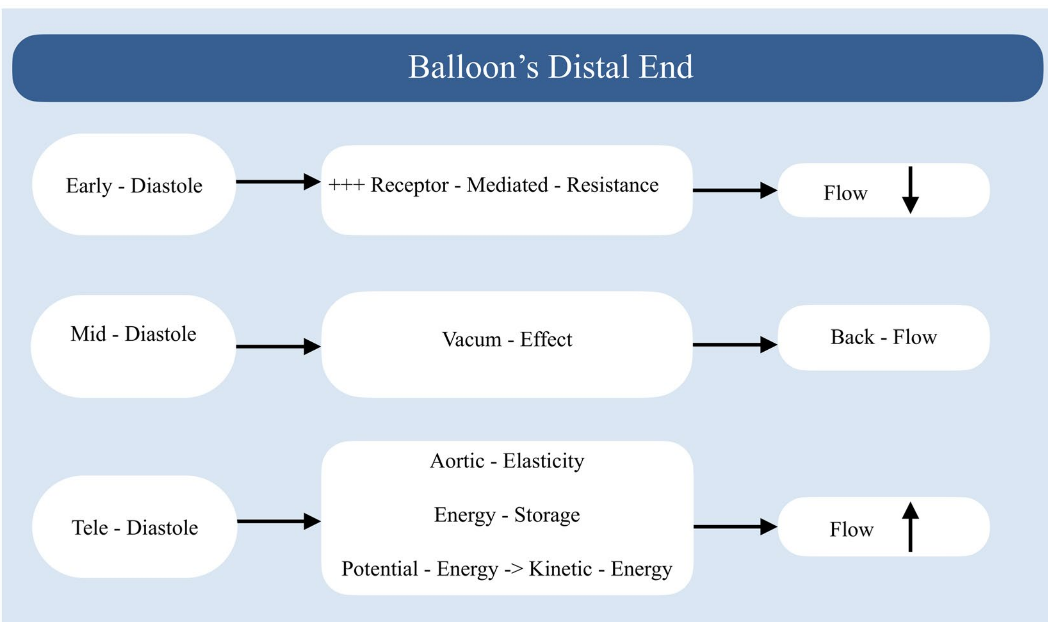

FIGURE 1 Flow patterns in the distal end of the intraaortic balloon [Color figure can be viewed at wileyonlinelibrary.com]

mainly related to the increase in local receptor-mediated vascular resistance.[15] More specifically, mediated Na+ channels and Ca^{2+} voltage-gated channels are involved in such a myogenic control that it is overcome by the action of the balloon within the bloodstream, with the final results of local smooth muscle contraction.[17]

4 | OTHER DESIGNS

Alternative designs have been proposed. In a multi-comparison study, the hemodynamic performance of six new IABP shapes was compared in vitro to the traditional cylindrical design.[18] The new shapes were based on the classic cylindrical shape. Still, a conical segment substituted 1/3, 1/2, or 2/3 of their total length: in the "oblance configurations," there was an increasing diameter from base to tip of 2/3, 1/3, and 1/2 (Types 1,3,5). In contrast, in the "lance configurations," there was a decreasing diameter from base to tip of 2/3, 1/3, and 1/2 (types, 2,4,6). Noncylindrical shapes showed improved hemodynamics compared to cylindrical IABPs.

Nonetheless, some shapes performed better at inflation, while others performed better at deflation. Based on these findings, the authors suggested patient-targeted shapes depending on the indication for IABP.[18] Another group tested an ascending aorta balloon pump, compared to the standard descending IABP.[19] The ascending aortic balloon increased the myocardial blood flow more than the standard descending IABP without a detrimental effect on cerebral perfusion.

5 | CONCLUSIONS

More research on this topic is warranted to find the significant pieces of the puzzle still missing. For instance, a pivotal point to explore is the type of flow below the balloon and toward the visceral arteries since the presence of any nonphysiological bloodstream would require a higher perfusion pressure to drive the flow into the mesenteric branches.[20] Also, more has to be understood on the interaction of the distal part of the balloon, during inflation and deflation, with the three components of the local regulatory system: intrinsic (local metabolic and myogenic), extrinsic (autonomic nervous system), and humoral (local or circulating vasoactive substances).[9] Most in vitro and in vivo experiments share the limitation of being performed in young animals. The aorta of the elderly population using IABP therapy is likely to be very stiff, and its expansion to accommodate the volume displaced by the balloon is rather small. Therefore, aorta recoiling and converting the potential to kinetic energy, although theoretically plausible, has to be further demonstrated.

"Looking at the other side" of the IABP not only will help to reduce the incidence of visceral ischemia, but it will also be a guide for new balloon designs that will allow enhanced performance and improved outcomes.

We suggest studying the flow below the balloon in a similar way to the proximal part in terms of hemodynamic effects following IABP compression and expansion as well as of the wave propagation.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest with the contents of this article.

AUTHOR CONTRIBUTIONS

All authors contributed equally to the writing of this manuscript.

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