The patient is a 63-year-old man with stage D heart failure and a left ventricular ejection fraction of <20% who presented to the Houston Methodist Hospital with cardiogenic shock. As a part of his care, he underwent placement of an intra-aortic balloon pump (IABP). The IABP settings were for the balloon to inflate with the aortic dicrotic notch and to deflate near the end of diastole. After assessment of his heart failure status, the decision was to proceed with cardiac transplant evaluation, and he underwent routine pretransplant screening that included carotid Doppler ultrasonography. On ultrasound, he was found to have mild calcified atherosclerotic plaque in the left internal carotid artery and left bulb and the left external carotid artery without hemodynamically significant stenosis (<50%). The right carotid arteries were not interrogated because of the presence of a Swan–Gantz catheter and overlying bandages. The Doppler signal in the left internal carotid artery was consistent with the presence of mechanical flow augmentation from the IABP as evidenced by the second forward pulsation seen on pulsed wave Doppler (Figure 1). However, in addition to the second forward signal from IABP augmentation, there was also a notable flow reversal seen during mid to late diastole corresponding with active deflation of the balloon pump (Figure 1). It is clear that this flow reversal was caused by the IABP as it was absent when the IABP was placed on standby. After identifying this finding, bedside Doppler was again performed in the common carotid artery with the IABP on standby, 2:1, 3:1, and with deflation optimized to the absolute end of diastole (Figure 2). After acquiring signals, the net forward time velocity integral (TVI) for each setting was determined (Table). Balloon deflation was optimized by moving deflation to the absolute end of diastole. After optimization of IABP deflation timing, the combined native and augmented forward TVI was equivalent to the forward TVI with the balloon on standby (Table). Transcranial Doppler was performed after deflation adjustment and demonstrated no evidence of intracranial flow reversal.

Discussion

This case demonstrates clear evidence of IABP-mediated iatrogenic flow reversal in the carotid arteries. To our knowledge, this is the first report to suggest that changing IABP deflation timing may influence the degree of flow reversal. Although this finding certainly warrants further investigation, there are significant implications for management of IABP deflation timing.

Understanding the effect of IABP timing on cerebral blood flow is an important aspect of clinical care, especially as IABPs are now used as bridge to transplant and may remain in place for weeks to months. Late diastolic IABP flow reversal was first described in 1990 when transcranial Doppler was used to evaluate cerebral blood flow in 3 patients with an IABP. An additional study suggested that iatrogenic IABP-related flow reversal in intracranial vessels may to occur in up to 35% of cardiac surgery patients supported with an IABP. The pulse-wave Doppler findings in this patient case are consistent with previous descriptions of IABP-mediated flow reversal. The case clearly demonstrates that flow reversal was a consequence of IABP inflation/deflation as carotid flow reversal was not seen while the IABP was on standby and flow reversal was also not seen in the beats without IABP inflation when the IABP was set to 1:2 or 1:3.

There are important observations from the Doppler signal acquisition in this case. First, the overall forward native beat TVI in the common carotid artery was decreased with IABP support when compared with the native beat TVI in the common carotid artery after the IABP was on standby for 2 minutes. This is shown best in the Table when the patient is on 2:1 support. Second, some of the additional forward flow gained by IABP inflation was matched by flow reversal during late diastole (also shown in the Table). The only IABP setting in which the net forward TVI was equivalent to the forward TVI with the balloon on standby was when deflation was timed carefully to the absolute end of diastole. However, even with this timing, there was a brief period of flow reversal. Unfortunately, transcranial Doppler assessment was performed only after deflation timing was changed, and we were not able to document evidence of cerebral blood flow reversal on transcranial Doppler. However, the fact we did not see evidence of cerebral blood
flow reversal suggests that changes in deflation timing may have eliminated intracranial flow reversal.

In conclusion, this case demonstrates that IABP deflation timing can influence IABP-mediated iatrogenic flow reversal in the common carotid artery. When deflation was timed carefully to end of diastole, the net forward flow (as assessed by TVI) in the common carotid artery was the same as the forward flow with the IABP on standby. This case highlights the potential importance of careful IABP deflation timing adjustment. Further investigation is needed to better understand the influence of IABP inflation/deflation timing on cerebral blood.

### Table. TVI of Individual Components of the Doppler Waveform in the Common Carotid

<table>
<thead>
<tr>
<th>IABP Setting</th>
<th>TVI Forward, cm</th>
<th>TVI Reverse, cm</th>
<th>Forward/Reverse Ratio</th>
<th>Total Forward TVI, cm</th>
<th>PSV, cm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standby*</td>
<td>22</td>
<td>None</td>
<td>Not applicable</td>
<td>22</td>
<td>96</td>
</tr>
<tr>
<td>2:1 (IABP augmented component)</td>
<td>24.5</td>
<td>4</td>
<td>6.1</td>
<td>20.5</td>
<td>100</td>
</tr>
<tr>
<td>2:1 (native heart component)</td>
<td>14.5</td>
<td>None</td>
<td>Not applicable</td>
<td>14.5</td>
<td>87</td>
</tr>
<tr>
<td>Optimized deflation timing</td>
<td>24.6</td>
<td>2.6</td>
<td>9.5</td>
<td>22</td>
<td>99</td>
</tr>
<tr>
<td>Near end-diastole deflation</td>
<td>25.5</td>
<td>7.9</td>
<td>3.2</td>
<td>17.6</td>
<td>99</td>
</tr>
</tbody>
</table>

Findings demonstrated that only when deflation is delayed to near end diastole is the total forward flow TVI (forward minus reverse) equal to the TVI with the balloon on standby. IABP indicates intra-aortic balloon pump; PSV, peak systolic velocity; and TVI, time velocity integral.

*Standby TVI obtained after 2 min on standby.

### Disclosures
Dr Estep has served as a consultant for Maquet and has served as a faculty speaker forDatascope. The other authors report no conflicts.

### References

Key Words: carotid arteries ■ cerebral blood flow ■ heart failure ■ intra-aortic balloon pumping ■ ultrasonography
Figure 1: Baseline Doppler imaging of the left external (ECA) and left internal (ICA) carotid artery and the left vertebral artery. Yellow arrows show iatrogenic flow reversal from the intra-aortic balloon pump, and red arrows indicate forward flow from balloon inflation. Right carotid was not interrogated because of the presence of a Swan–Gantz catheter and overlying bandages obstructing view.

Figure 2: Doppler signals obtained in the common carotid artery on different intra-aortic balloon pump settings. The following tracings are electrocardiography triggered with inflation–deflation timing adjusted manually. Velocities above the yellow line show the normal cranial direction of blood flow, whereas velocities below the line show flow reversal.
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