recorded blood pressures is of particular concern, as duration of intraoperative hypotension has been shown to correlate with acute kidney injury, among other adverse outcomes.[3,4] Given the low incidence of complications associated with radial arterial line placement and the high incidence of intraoperative hypotension in this population, we would argue that arterial line placement is underutilized in the perioperative management of these patients.[5]

Competing Interests

The authors declare no competing interests.

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Noninvasive Blood Pressure Determination in Left Ventricular Assist Device Patients

To the Editor:

We read with great interest the intriguing study by Mathis *et al.*[1] involving 702 noncardiac procedures performed in patients with left ventricular assist devices (LVADs). We commend the authors for their work in this important area and share their passion and enthusiasm for caring for LVAD patients perioperatively.

Mathis *et al.* reported that arterial line blood pressure (BP) was utilized in 20% of cases, with the remaining relying on noninvasive BP monitoring modalities. Interestingly, they report that 55% of all anesthetics had a greater than 20-min gap intraoperatively without a documented BP reading. Even more alarming is that 48% of their anesthetics had BP monitoring for less than 20% of minutes intraoperatively, and 31 cases lacked any BP recordings entirely. Further, in cases where an arterial line was employed, they report a monitoring gap of greater than 20 min in 32% of anesthetics occurring primarily between induction of anesthesia and arterial line placement. It is not reported in the manuscript whether the placement of arterial access was necessitated by the inability to obtain noninvasive BP readings or whether it was anticipated based upon patient and/or surgical factors. Mathis *et al.* stated that when BP was not recorded, "measures approximating vital organ perfusion were documented, including patient responsiveness (*e.g.*, patient following commands, patient alert, *etc.*) in 11 cases and/or serial documentation of stable LVAD parameters (*i.e.*, flow, power, and pulsatility index) in 29 cases."

We previously reported that arterial line BP monitoring was used in 66% of LVAD patients undergoing general anesthesia for noncardiac surgery at our institution.[2] In LVAD patients undergoing exclusively gastrointestinal endoscopy principally without general anesthesia, we reported arterial line use in only 10% of procedures.[3] In 6% of these anesthetics, the BP was not charted or documented as inaccurate.

The American Society of Anesthesiologists Standards for Basic Anesthetic Monitoring state "every patient receiving anesthesia shall have arterial BP and heart rate determined and evaluated at least every five minutes," with exceptions permitted "under extenuating circumstances."[4] Continuous-flow LVAD patients present many perioperative challenges including BP monitoring. One study evaluated various noninvasive BP modalities in continuous-flow LVAD patients and found that the success rate of obtaining a BP reading with an automated BP cuff was 53%, Doppler BP 94%, auscultation 14%, and palpation 3%.[5] In our experience, although noninvasive BP determination (particularly with automated cuffs) may be initially possible in LVAD patients, preload and afterload can change markedly and rapidly intraoperatively. These fluctuations may result in a significant decrease in pulsatility with subsequent loss of reliable and accurate noninvasive BP readings. For this reason, we strongly believe that if noninvasive BP determination (especially an automated BP cuff) is utilized, then a more reliable modality to determine BP should be immediately available in the anesthetizing location such as Doppler BP or the ability to expeditiously place invasive arterial line BP monitoring. In teaching institutions such as ours, this often entails educational efforts in modalities such as Doppler BP determination and the limitations of automated BP cuffs that may be unfamiliar to the wide variety of noncardiac anesthesia providers who help care for LVAD patients perioperatively. When use of invasive arterial BP monitoring is planned intraoperatively, consideration should be made for placement before induction of anesthesia to avoid monitoring gaps postinduction should noninvasive BP determination attempts become unsuccessful. In cases where the functionality of noninvasive BP modalities

was confirmed before induction of anesthesia, the inability to determine BP intraoperatively should prompt clinicians to rapidly employ a different modality that ensures reliable BP determination so that large gaps devoid of BP readings do not occur during an anesthetic. Finally, given the frequent difficulty reported by Mathis *et al.* in determining BP intraoperatively in the majority of anesthetics, perhaps unrecognized and untreated hypotension could have also contributed to the primary outcome of acute kidney injury.

Competing Interests

The authors declare no competing interests.

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In Reply:

We thank Drs. Barbara and Freundlich *et al.* for their thoughtful responses to our recent article.[1] In their responses, they highlight critical points regarding the management of patients with left ventricular assist devices (LVADs) presenting for noncardiac surgery. These points include: (1) LVAD patients are at high risk for perioperative complications; (2) frequency of invasive arterial line monitoring continues to decrease, despite high rates of intraoperative monitoring gaps; (3) potential hemodynamic instability in the setting of inadequate blood pressure monitoring may lead to increased incidence of complications (including acute kidney injury); and, as such, (4) alternatives to automated noninvasive cuff measurements for blood pressure monitoring must be more aggressively pursued.

We agree with Drs. Barbara and Freundlich that the LVAD population is, by definition, high risk and that a decreasing frequency of arterial line monitoring observed over our study period is not justified by the high rate of blood pressure monitoring gaps also observed. We support arterial line placement for major procedures requiring general anesthesia in this population; however, we highlight alternatives to routine arterial line use for minor procedures with sedation, as alluded to in Dr. Barbara's and Dr. Freundlich's responses.

With the increased prevalence of LVAD patients presenting for noncardiac procedures, rapidly growing demands are placed on limited anesthesiology department resources. Arterial line placement can occasionally be a technically challenging, time-consuming task in the LVAD patient, often requiring ultrasound guidance in the setting of nearly nonpulsatile blood flow. While we do not discourage such attempts, we *strongly* encourage anesthesiologists to seek access to—and develop a familiarity with—other means of blood pressure monitoring, most notably a Doppler cuff. In the LVAD population, Doppler measurements demonstrate success rates of 91 to 100%, a vast improvement upon automated cuff measurements (50 to 63%).[2–4] As a result of these findings, we have developed a staff education program at our institution to improve departmental awareness and access to Doppler devices for the specific purpose of LVAD patient monitoring; we support efforts to do the same among institutions caring for LVAD patients.

With regards to the context of arterial line usage and monitoring gaps observed, we acknowledge limitations of the retrospective nature of our study. Anesthesiologist justification for arterial line use, whether planned or unplanned, was unavailable for study. In most instances of gaps in monitoring, gaps occurred after induction of anesthesia; in such cases, we can speculate that the monitoring gap may have been associated with an automated cuff failure in the setting of decreased preload or afterload and diminished pulsatility. Beyond seeking a means of improved blood pressure monitoring, it has been our experience in caring for LVAD patients that efforts to maintain pulsatility—including judicious fluid boluses and vasopressor administration concurrent with gentle induction of anesthesia—can often successfully maintain automated cuff monitoring capability and prevent unrecognized hypotension.

In addition to a familiarity with blood pressure monitoring in the LVAD population, we encourage *all* anesthesiologists to become familiar with basic settings for continuous-flow LVADs, including pump flow, speed, power, and pulsatility index.[5] Although we describe an association between intraoperative hypotension and acute kidney injury in our study, a correlation between LVAD pump flows and outcomes remains understudied. Pump flow generated by a specific pump speed may be a sensitive indicator of the balance between preload and afterload and may be a useful aid in patient management. Finally, no hemodynamic parameters monitored should serve to replace an understanding of the pathophysiology of the preload-dependent, afterload-sensitive LVAD patient; such an understanding remains equally important in clinical decision making.

In conclusion, we thank Drs. Barbara and Freundlich *et al.* for their valuable feedback regarding our study. Although