INTRODUCTION

Although noninvasive blood pressure measurement (NIBP) is recognized as the standard monitoring modality in most clinical settings for blood pressure control, arterial blood pressure (ABP) monitoring with intra-arterial catheters may be necessary in settings that require more accurate, beat-to-beat blood pressure monitoring or easy access for arterial blood sampling. This invasive method for blood pressure monitoring may be required in cases in which patients are subject to acute hemodynamic changes, such as trauma, cardiac, vascular, chest, and neurosurgical procedures; cases that require frequent arterial blood samples for management of blood gas, blood chemistry, and coagulation abnormalities; and for patients who have comorbidities such as heart failure or cerebrovascular disease, which may compromise their ability to tolerate hemodynamic fluctuations. Intra-arterial hemodynamic monitoring is also often indicated in critically ill patients because it facilitates proper administration and titration of vasopressors and inotropes and may prevent clinically significant fluctuations in hemodynamics from going unnoticed for a significant period of time. Despite this, the purported benefits that can be offered by intra-arterial

Background: Despite the lack of guidelines regarding the use of intra-arterial lines in postmastectomy breast reconstruction (PMBR), they continue to be used in this setting. In this study of patients undergoing PMBR, we aimed to (1) identify factors associated with intra-arterial line placement, (2) analyze the correlation between intra-arterial monitoring and noninvasive blood pressure (NIBP) monitoring, and (3) investigate whether hemodynamic management differs significantly between patients undergoing intra-arterial blood pressure monitoring versus NIBP.

Methods: All patients undergoing flap-based PMBR between 2017 and 2019 were retrospectively reviewed. Patients were pair-matched based on flap donor site, BMI, and age to identify factors associated with intra-arterial line placement. Methods described by Bland and Altman were utilized to determine agreement between intra-arterial line measurements and NIBP.

Results: Thirty-two patients were included with 16 patients in the intra-arterial line group and 16 in the NIBP group. None of the factors studied were significantly related to the likelihood of intra-arterial line placement. Agreement analysis demonstrated that mean arterial pressures calculated from intra-arterial line readings were as much as 23 points lower or 12 points higher than those from NIBP. Bias calculations with this extent of difference suggest poor correlation between intra-arterial line readings and NIBP. There was no difference between groups in rate of administration of blood-pressure altering medications (hypertensive: \( n = 3, 18.8\% \), \( P = 1.000 \); hypotensive: \( n = 7, 3.8\% \), \( P = 1.000 \)).

Conclusion: Our findings highlight the need for more definitive guidance regarding the use of intra-arterial monitoring in patients undergoing PMBR. (Plast Reconstr Surg Glob Open 2021;9:e3284; doi: 10.1097/GOX.0000000000003284; Published online 21 January 2021.)
monitoring in ICU patients have been called to question by research suggesting that invasive monitoring may not actually lead to reductions in in-hospital mortality.9

Intra-arterial blood pressure monitoring is not without associated risks. A retrospective study9 of over 57,700 patients undergoing intra-arterial cannulation revealed a complication rate of 3.4 per 10,000 (0.03%), but there is also evidence8 to suggest that minor complications such as temporary artery occlusion and hematoma may occur more often. Although major complications are rare, these adverse events must be carefully considered when choosing to use intra-arterial monitoring versus less-invasive monitoring techniques. Minor complications include temporary occlusion of the cannulated artery, pseudoaneurysm, arteriovenous fistula formation, air embolism, infection, hematoma, and minor bleeding, whereas more serious complications include nerve paralysis or permanent ischemic damage requiring amputation.3,15

The radial, brachial, axillary, femoral, and dorsalis pedis arteries can be used for intra-arterial catheterization; however, the radial artery is most commonly used because it is both accessible and has collateral blood supply from the ulnar artery and palmar branches.2,3,10 It is of note, however, that the incidence of an incomplete superficial palmar branch, which may increase the risk of ischemic complications due to insufficient collateral blood flow, has been cited to be as high as 46%.3,11 Furthermore, although the patency of collateral circulation can be assessed with the Allen test,6 the clinical accuracy of this test has been called into question by various studies.3,12,13 The test involves compressing the radial and ulnar arteries while the patient clenches his/her fist. Dominant blood supply to the hand can theoretically be determined as pressure is released from each individual artery.7 Jarvis et al identify several possible limitations of the Allen test, including a lack of consensus on what comprises a positive test, observer bias, and methodologic errors, all of which contribute to the authors’ conclusion that the test is unreliable.10 The high frequency of variation in blood supply, coupled with unreliable diagnostic testing, makes it more difficult to depend on the radial artery as a safe site for cannulation.

There are currently no guidelines to inform the use of intra-arterial blood pressure monitoring during postmastectomy breast reconstruction (PMBR), which includes a range of prosthetic and autologous reconstructive procedures following mastectomy. In the absence of significant comorbidities or other possible complications, PMBR generally does not meet any of the aforementioned indications for intraoperative invasive blood pressure monitoring. Despite the known risks associated with ABP monitoring and the lack of guidelines for its use, intra-arterial lines continue to be used for intraoperative hemodynamic monitoring in various reconstructive procedures. In this study, we aimed to investigate the use of intra-arterial lines versus NIBP monitoring during PMBR. Using a paired-matched cohort of patients undergoing PMBR, we specifically compare (1) factors associated with the decision for intra-arterial line placement, (2) the correlation between hemodynamic measures obtained from ABP versus NIBP, and (3) the relationship between monitoring method and administration of blood pressure altering medications.

MATERIALS AND METHODS

Study Design

This was a retrospective review of all patients who underwent breast reconstruction between 2017 and 2019. Patients were then excluded if an intra-arterial line was placed at the beginning of the operation but not maintained throughout the duration of the case. Patients were divided into groups based on method of blood pressure monitoring: intra-arterial (A-line) or noninvasive (NIBP). Patients were then pair-matched based on reconstructive flap donor site and age to identify relationships between certain factors and the decision for intra-arterial line placement. This study was approved by the Institutional Review Board (MHRI 2018-173).

Data Collection

Anesthesia records were retrospectively reviewed for documentation of intra-arterial line placement and readings. When an intra-arterial line was placed, the first 10 readings that correlated to an NIBP reading within 5 minutes were recorded. Various time lengths were assessed, including total time in the operating room (patient in, patient out), total anesthesia time (anesthesia in, anesthesia out), and total surgical time (incision start, closing end). Systolic and diastolic blood pressure ranges were recorded for each patient. Demographic and comorbidity information—including age, ethnicity, Body Mass Index (BMI), smoking history, Charlson Comorbidity Index (CCI), and American Society of Anesthesiologists (ASA) physical status classification—were also collected.

Statistical Methods

Continuous variables were described by means and SDs. Differences in the averages of continuous variables between the NIBP and intra-arterial line groups were compared using a paired t-test. Categorical variables were described by frequencies and percentages, and differences between the NIBP and intra-arterial line groups were compared with the McNemar test. Symmetry testing was used to examine differences between paired proportions for multi-category variables. P < 0.05 was considered to indicate statistically significant differences. Statistical analysis was performed with SAS 9.4 (SAS Institute Inc., Cary, N.C.).

Agreement between intra-arterial line measurements and NIBP were determined using methods previously explained by Bland and Altman.3 Univariate analysis was performed to identify variables significantly related to intra-arterial line placement. All variables found to be significant were incorporated into a multivariate model for intra-arterial line placement.

RESULTS

Demographics

A total of 182 patients were identified as those who underwent PMBR between 2017 and 2019. Four patients who had an intra-arterial line initially placed but not maintained throughout the operation were excluded, leaving 178 patients for analysis. An estimated 16 patients
with intra-arterial lines were identified. Pair-matching based on age, BMI, and reconstructive flap donor site yielded 2 groups (intra-arterial line and NIBP), with 16 patients each. All patients underwent PMBR with deep inferior epigastric artery flaps. In each group, 7 patients underwent delayed reconstruction and 9 patients underwent immediate reconstruction. Summary statistics for all patients studied (n = 32) is presented in Table 1. Mean age at the time of surgery was 54.1 (SD 11.7). Mean BMI was 29.1 (SD 4.5) and mean CCI was 3.1 (SD 1.2). The vast majority of patients were African American (56.3%) or White (34.4%). There were no significant differences between intra-arterial line and NIBP groups with respect to demographics or comorbidities, including ASA class (Table 1).

Characteristics Associated with Intra-arterial Line Placement

Univariate analysis of the 32 pair-matched patients showed that none of the demographic characteristics (age at the time of surgery, \(P = 0.68\); race, \(P = 0.57\)) or comorbidities (BMI, \(P = 0.66\); CCI, \(P = 1.00\); ASA, \(P = 0.57\); smoking history, \(P = 0.06\)) were significantly related to the likelihood of intra-arterial line placement. Total time in the operating room (\(P = 0.33\)), total anesthesia time (\(P = 0.33\)), and total surgery time (\(P = 0.32\)) were also not significantly related to likelihood of intra-arterial line placement.

Relationship between Intra-arterial Line and NIBP Measurements

The agreement analysis indicates that mean arterial pressure calculated from intra-arterial line readings were as much as 23 points lower or 12 points higher than those from NIBP. Bias calculations with this degree of difference indicate a poor correlation between intra-arterial line readings and NIBP (\(R^2 = 0.45\), Fig. 1).

Administration of Blood Pressure Altering Medications

When comparing blood pressure ranges between the 2 groups, significant differences were identified for the upper limit of systolic blood pressure values (NIBP mean 169.2 versus intra-arterial mean 158.0; \(P < 0.01\)) and the upper limit of diastolic blood pressure values (NIBP mean 91.4 versus intra-arterial mean 81.3, \(P = 0.02\)) (Table 1). Despite these differences, both groups had equal rates of administering antihypertensive medication (n = 3, 18.8%, \(P = 1.000\)) and hypotension-reducing medication (n = 7, 43.8%, \(P = 1.000\)), as shown in Table 2. The only antihypertensive medications administered in the studied population were beta blockers, with the most common being esmolol and labetalol, with doses ranging from 10mg to 60mg. Hypotension-reducing medications administered in the study population included up to 2.7mg of phenylephrine and up to 35mg of ephedrine.

Complications

Three total patients required takeback to the operating room for hematom evacuation, and 1 patient required takeback for flap failure. None of the patients with intra-arterial line placement experienced injury or complications associated with cannulation, and no patients experienced NIBP-associated complications. There were no statistically significant differences between the 2 groups with respect to incidence of complications.

DISCUSSION

The Standards for Basic Anesthetic Monitoring laid out by the American Society of Anesthesiologists requires every patient receiving anesthesia to have their arterial blood pressure and heart rate evaluated every 5 minutes, at a minimum.\(^4\) In addition, every patient undergoing general anesthesia must have their circulatory function

Table 1. Summary Statistics

|                          | Overall         | NIBP              | Intra-arterial Line |
|--------------------------|-----------------|-------------------|---------------------|
|                          | Mean  | SD    | Mean  | SD    | Mean  | SD    | P     |
| Age at surgery           | 54.1  | 11.7  | 55.7  | 13.3  | 54.6  | 10.3  | 0.68  |
| BMI                      | 29.1  | 4.5   | 28.7  | 4.9   | 29.4  | 4.2   | 0.66  |
| CCI                      | 3.1   | 1.2   | 3.1   | 1.3   | 3.2   | 1.1   | 1.00  |
| Total operating room (min) | 507.5 | 107.6 | 488.3 | 103.7 | 526.7 | 111.4 | 0.33  |
| Total anesthesia (min)   | 520.1 | 107.9 | 500.6 | 103.0 | 539.6 | 112.4 | 0.33  |
| Total surgery (min)      | 451.2 | 109.6 | 431.4 | 106.0 | 470.9 | 112.9 | 0.32  |
| SBP range                |        |       |       |       |       |       |       |
| Highest                  | 153.6  | 26.3  | 169.2 | 27.1  | 138.0 | 13.4  | <0.01 |
| Lowest                   | 86.5   | 26.4  | 90.9  | 34.0  | 82.0  | 15.4  | 0.35  |
| DBP range                |        |       |       |       |       |       |       |
| Highest                  | 86.3   | 12.1  | 91.4  | 12.4  | 81.3  | 9.9   | 0.02  |
| Lowest                   | 46.9   | 8.5   | 47.3  | 7.6   | 46.6  | 9.5   | 0.81  |
| ASA class                |        |       |       |       |       |       | 0.57  |
| 1                        | 3.1%   | (n = 1)| 6.3%  | (n = 1)| 0%    | (n = 0)| 0.90  |
| 2                        | 56.3%  | (n = 18)| 62.5% | (n = 10)| 50%   | (n = 8)| 0.88  |
| 3                        | 40.6%  | (n = 13)| 31.3% | (n = 5) | 50%   | (n = 8)| 0.80  |
| Race                     |        |       |       |       |       |       | 0.57  |
| African American         | 56.3%  | (n = 18)| 62.5% | (n = 10)| 50.0% | (n = 8)| 0.88  |
| White                    | 34.4%  | (n = 11)| 25.0% | (n = 4) | 43.8% | (n = 7)| 0.74  |
| Other                    | 9.4%   | (n = 5) | 12.5% | (n = 2) | 6.5%  | (n = 1)| 0.06  |
| Smoking history          |        |       |       |       |       |       |       |
| Yes                      | 28.1%  | (n = 9) | 12.5% | (n = 2) | 43.8% | (n = 7)| 0.74  |
| No                       | 71.9%  | (n = 23)| 87.5% | (n = 14)| 56.3% | (n = 9)| 0.88  |

ASA, American Society of Anesthesiologists; BMI, body mass index; CCI, Charlson Comorbidity Index; DBP, diastolic blood pressure; NIBP, non-invasive blood pressure; SBP, Systolic Blood Pressure.
periodically evaluated via monitoring of an intra-arterial pressure tracing, ultrasound peripheral pulse monitoring, oximetry, pulse plethysmography, palpation of a pulse, or auscultation of heart sounds. Outside these standards, there are few, if any, guidelines for the use of intra-arterial lines for intraoperative hemodynamic monitoring, particularly in reconstructive surgery such as PMBR.

Continuous hemodynamic monitoring and arterial access provided by intra-arterial catheterization are certainly indicated in certain procedures and specific patient populations. In theory, then, certain patient characteristics should serve as good predictors for use of intra-arterial lines: the more comorbidities a patient has, the more likely he or she should undergo invasive blood pressure monitoring. In a study examining the use of invasive blood pressure monitoring in patients undergoing total shoulder arthroplasty, Gabriel et al found that patients over the age of 65 and/or with congestive heart failure (CHF) were more likely to undergo hemodynamic monitoring with intra-arterial lines. In our study of patients who underwent PMBR, neither age nor CCI had a significant relationship to intra-arterial line use. This finding highlights the need for more specific guidelines regarding the use of intra-arterial lines intraoperatively, particularly in reconstructive procedures.

One of the proposed benefits of intra-arterial blood pressure monitoring is its superior precision when compared with that of NIBP. We found a poor correlation between measurements obtained via intra-arterial line readings and NIBP. Similar findings have been reported in the literature by Cambiaso-Daniel et al and Joffe et al; however, these studies were limited to pediatric patients. These findings suggest that intra-arterial blood pressure monitoring should be used in the place of NIBP in cases where accuracy of measurements is paramount.

The complications associated with intra-arterial catheterization are rare, but exist nonetheless. As few as <1.0% of patients will experience major complications with ABP monitoring, but the incidence of minor complications with radial artery catheterization, such as temporary occlusion of the artery, has been cited to be as high as 35%. Despite its known complications, invasive blood pressure monitoring is indicated in certain procedures and with certain patient populations in which the benefits to use outweigh these risks. One such benefit is the possibility for tighter hemodynamic control: more frequent and accurate blood pressure readings would allow for stricter adjustments of blood pressure with appropriate medications. And yet, in our study, we found that there was no significant difference between groups in the rate of administering blood pressure altering drugs. Although this finding does not discount this potential benefit of invasive blood pressure monitoring, it does call to question whether this

| Table 2. Blood Pressure Altering Medications Administered in NIBP versus Intra-arterial Line Patient Groups |
|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|-----------------|
|                                                             | Overall                                                       | NIBP                                                         | Intra-arterial Line                                           | P               |
| Hypertensive meds admin                                      | n                | %                | n                | %                | n                | %                | 1.00 |
| Yes                                                          | 6                | 18.8             | 3                | 18.8             | 3                | 18.8             |      |
| No                                                           | 26               | 81.3             | 13               | 81.3             | 13               | 81.3             |      |
| Hypotensive meds admin                                       | n                | %                | n                | %                | n                | %                | 1.00 |
| Yes                                                          | 14               | 43.8             | 7                | 43.8             | 7                | 43.8             |      |
| No                                                           | 18               | 56.3             | 9                | 56.3             | 9                | 56.3             |      |

Fig. 1. Mean arterial pressure (MAP) readings in patients with intra-arterial lines versus NIBP.

Table 2. Blood Pressure Altering Medications Administered in NIBP versus Intra-arterial Line Patient Groups

| Hypertensive meds admin | Overall | NIBP | Intra-arterial Line | P |
|-------------------------|---------|------|--------------------|---|
| Yes                     | 6       | 18.8 | 3                  | 18.8 | 3 | 18.8 | 1.00 |
| No                      | 26      | 81.3 | 13                 | 81.3 | 13 | 81.3 |      |
| Hypotensive meds admin  |         |      |                    |     |    |      | |
| Yes                     | 14      | 43.8 | 7                  | 43.8 | 7 | 43.8 | 1.00 |
| No                      | 18      | 56.3 | 9                  | 56.3 | 9 | 56.3 |      |
particular benefit is applicable to patients undergoing PMBR. Wax et al demonstrated that patients undergoing simultaneous NIBP and invasive blood pressure monitoring received fewer vasopressors and antihypertensives when compared with patients who had only invasive blood pressure monitoring.\(^\text{1,2}\) In our study, patients with intra-arterial lines were concomitantly evaluated with NIBP; it is possible, therefore, that a more significant difference in administration of blood pressure altering medications may have been revealed in our study, had the intra-arterial line group been monitored exclusively with ABP and not along with NIBP.

As a pair-matched retrospective review, our study is inherently limited. Our sample size was limited in number and must be taken into account when considering the generalizability of these results. In addition, our study population was relatively healthy. Although this may accurately reflect the larger population of patients who underwent PMBR, it may be less reflective of the general health of patients who underwent other reconstructive surgeries. Furthermore, the relative lack of comorbidities in our patient population (outside age over 50 and solid tumor) limited our regression modeling to examining the relationship between overall CCI (rather than individual comorbidities such as CHF) and odds of intra-arterial line placement. Future studies may reveal that intra-arterial lines are of measurable benefit in PMBR or other reconstructive procedures that are performed on patients with a greater comorbidity burden.

**CONCLUSIONS**

Although invasive blood pressure monitoring may allow for more precise hemodynamic measurements intraoperatively, the findings of this study demonstrate that in the setting of PMBR, this enhanced precision does not seem to drastically affect the hemodynamic management of patients. In addition, neither patient demographics nor comorbidity burden can reliably predict whether or not intra-arterial lines will be placed in patients undergoing PMBR. These findings highlight the need for more specific guidance regarding the use of intra-arterial lines for PMBR as well as other reconstructive procedures more generally.

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