INTRODUCTION

Free tissue transfer techniques for postmastectomy reconstruction are vital to the eventual aesthetic outcome for breast cancer patients. Free flap reconstruction is dependent on the critical microsurgical techniques that are employed, which, if they were to fail, the subsequent flap failure can be devastating from both a practical and cosmetic standpoint. Flap monitoring is necessary to identify a flap at risk of failure early in the postoperative setting. Up to 50% of flaps can be salvaged with prompt recognition of compromise through existing clinical monitoring methods.1

The current monitoring systems available include Doppler monitoring with clinical exam, implantable Doppler, near-infrared spectroscopy (NIRS), and indocyanine green injections.1 The use of tissue oximetry monitoring has become a common practice to facilitate detection of poor flap perfusion.1 A recent study by Koolen et al2 found that postoperative continuous tissue oximetry monitoring of breast flaps led to increased salvage rates and decreased the rate of re-exploration and flap losses. Noninvasive tissue oximetry has the advantage of objectively identifying potential flap compromise before it manifests itself clinically.3

Venous anastomotic occlusion is a common risk factor for microvascular breast reconstruction failure.4 Furthermore, flap edema from aggressive fluid...
resuscitation may increase the interstitial pressure in areas surrounding critical choke vessels or capillaries that allow for perfusion and subsequent drainage of the flap. A previous retrospective study by Karamanos et al. analyzed the effects of liberal versus restrictive fluid resuscitation perioperatively. This study found that a restrictive fluid resuscitation strategy of less than 7 ml/kg/h for the first 24 hours after reconstruction was associated with improved flap perfusion and a lower incidence of wound complications.3

We hypothesized that tissue oximetry readings can guide real-time fluid administration in the postoperative period and improve perfusion in patients undergoing autologous breast reconstruction.

METHODS

After institutional review board approval, all patients who underwent a free flap breast reconstruction from 2015 to 2018 were identified from a prospectively collected database. The following CPT codes were used when patients were being included in the database: 19364 (Breast reconstruction with free flap) and S2068 (Breast reconstruction with deep inferior epigastric perforator flap or superficial inferior epigastric artery flap, including harvesting of the flap, microvascular transfer, closure of donor site and shaping of the flap into a breast). Variables known to impede wound healing and associated with flap complications were identified [diabetes, smoking history, body mass index (BMI), type of flap (DIEP versus muscle sparing free TRAM flap), immediate versus delayed reconstruction, history of prior abdominal surgery and use of radiation therapy or chemotherapy before reconstruction]. All decisions regarding the fluid management of the patients were based on the clinical evaluation of the attending surgeons and their treating teams.

The following exclusion criteria were applied: flaps that returned to the OR within the first 48 hours due to technical problems of the arterial or venous anastomoses. Each DIEP flap is being assessed for perfusion before ligating the inferior epigastric using intraoperative ICG and after the DIEP flap is completely raised. Any areas of hypoperfusion are marked and are removed to avoid postoperative complications. The institution’s protocol for postoperative management of free flap breast reconstruction is well established and followed by all faculty members. Monitoring of the flap perfusion is done every hour by physical examination by the nursing staff, by assessing the Doppler signal and by transcutaneous tissue oximetry (T-stat Spectros, Campbell, Calif.). As discussed above, T-stat measures hemoglobin saturation with oxygen and does not measure the oxygen tension. The sensor is loosely secured in place with tape and all subsequent readings are performed in the same area of the flap with each previous reading acting as its control for subsequent ones.

The study population was divided in two groups based on development of any flap complications. Mean transcutaneous oximetry readings of the first four postoperative days were recorded. The mean change at 24 hours from the original reading was calculated (ΔTO). The study population was divided on two groups based on whether administration of intravenous fluids (IVFs) was increased/maintained (group 1) or decreased (group 2) after POD 0. The decrease of IVF was at least 50% of the initial rate, whereas in most instances, fluids were discontinued completely with initiation of a diet. The change in the mean perfusion was tabulated for all patients.

The study group was then divided in two groups based on the trend of the flap perfusion as documented by means of tissue oximetry at the end of the first 24 hours postoperatively (ΔTO). The impact of postoperative fluid resuscitation on flap perfusion was assessed for both patients who experienced an improvement in flap perfusion documented by tissue oximetry (positive ΔTO) and for those who experienced a decrease in perfusion (negative ΔTO).

RESULTS

A total of 120 patients were identified. Patients with incomplete medical records, patients with pedicled autologous reconstruction, patients who underwent emergent exploration and anastomosis revision during the index hospitalization and patients with implant-based reconstruction were excluded from further analysis. Of those included in the study, 38 patients (32%) developed late flap related wound complications and 82 patients (68%) did not. These complications included partial flap necrosis requiring revision (8/38), dehiscence (4/38), fat necrosis (18/38), and infection (8/38). The mean age of the study population was 53 years with a mean BMI of 33. The vast majority of the patients were White (80%), followed by Hispanic (16%). A total of 31% of the patients received neoadjuvant chemotherapy, whereas 49% received adjuvant chemotherapy. Adjuvant radiation therapy was received by 14% of the patients. The vast majority of the patients underwent mastectomy due to breast cancer, whereas only 29% underwent immediate reconstruction (Table 1). When a univariate analysis was performed with the study population divided into liberal (≥7 ml/kg/h) versus restrictive (≤7 ml/kg/h) fluid administration, there was no different in the baseline characteristics between the two groups. These cut points were based on previously published literature.5,8

Table 2 depicts the perioperative fluid status for the study population. Patients who developed wound complications received more fluids intraoperatively. Similarly, their overall fluid status was more positive at the end of postoperative day 0, compared to patients who did not

### Takeaways

**Question:** Can tissue oximetry guide postoperative fluid administration to improve flap perfusion?

**Findings:** For patients who had a documented decrease in tissue oximetry at 24 hours, decreasing fluid administration resulted in better flap perfusion.

**Meaning:** In patients undergoing free tissue breast reconstruction, tissue oximetry readings may be used as a novel guide for postoperative fluid management.
develop wound complications. For patients who experienced a decrease in their tissue oximetry readings at the end of postoperative day 0 (negative delta), there was a correlation between the fluid balance and the subsequent development of complications. That correlation was not observed for patients that did not experience a decrease in their tissue oximetry readings (positive delta; Table 2).

Figure 1 depicts ∆TOR at different time points for the patient population, stratified the strategy employed with regards to their fluid management. The transcutaneous oximetry readings at 2, 4, 6, 8, 12, and 24 hours were examined. The patients who had their fluids decreased or discontinued, experienced a steady increase of their tissue oximetry readings (mean: +11 at the end of 72 hours, \( P < 0.05 \)). For people whose fluids were maintained or increased, a steady decrease in their flap perfusion as documented by tissue oximetry was noted (mean: −10 at the end of 72 hours, \( P < 0.05 \)).

Figure 2 shows the impact of fluid administration on patients who did not experience a decrease in their flap perfusion at the end of POD 0. The fluid administration strategy did not result in a change in the flap perfusion as documented by the tissue oximetry readings. On the contrary, for people who experienced a decrease in tissue perfusion as documented by the tissue oximetry, the decision on further fluid administration strategy had an impact on further flap perfusion. As depicted in Figure 3, patients who had their fluid administration decreased had a significant increase in the tissue oximetry readings while patients who had their fluids increased or maintained continued to experience a decrease in flap perfusion (Fig. 3). As a result, tissue oximetry readings at the end of postoperative day 0 were able to identify a subpopulation of patients who benefited from a decrease in further fluid administration as demonstrated by an increase in flap perfusion.

**DISCUSSION**

In this study, we analyzed retrospective data in patients undergoing free tissue breast reconstruction to identify the relationship between near infrared spectroscopy tissue oximetry readings and postoperative fluid management. A decrease in fluid administration following the initial 24 hours of surgery was found to be associated with improved tissue oximetry readings. In patients who experienced a decrease in their T stat readings within the first 24 hours, a subsequent decrease in the rate of fluid administration resulted in improved perfusion. Our findings suggest that T stat monitoring may guide fluid management in the early perioperative period and improve patient outcomes.

Understanding the factors that influence the hemodynamic status of microvascular anastomosis in free flap reconstruction are crucial for free flap survival and can help establish criteria that can guide postoperative management.29 Several studies have established the use of NIRS as an accurate and reliable means to detect vascular

### Table 1. Patients’ Demographics and Clinical Characteristics

|                        | Overall (n = 120) | Flap Complications (n = 38) | No Flap Complications (n = 82) | P       |
|------------------------|------------------|-----------------------------|-------------------------------|---------|
| Age (mean, SD)         | 53 ± 9           | 51 ± 9                      | 54 ± 8                        | 0.098   |
| BMI (mean, SD)         | 33.0 ± 5.5       | 32.1 ± 4.9                  | 34.3 ± 5.9                    | 0.184   |
| Race                   |                  |                             |                               |         |
| White                  | 96 (80.0)        | 29 (76.3)                   | 67 (81.7)                     |         |
| Hispanic               | 19 (15.8)        | 6 (15.8)                    | 13 (15.9)                     |         |
| African American       | 4 (3.3)          | 1 (2.6)                     | 5 (6.1)                       |         |
| Asian                  | 1 (0.8)          | 0 (0.0)                     | 1 (1.2)                       | 0.618   |
| History of smoking     | 37 (30.8)        | 15 (39.4)                   | 22 (26.8)                     | 0.061   |
| DM                     | 25 (20.8)        | 10 (26.3)                   | 15 (18.3)                     | 0.053   |
| Mastectomy for cancer  | 114 (95.0)       | 36 (95.0)                   | 78 (95.0)                     |         |
| Prophylactic mastectomy| 6 (5.0)          | 2 (5.0)                     | 4 (5.0)                       |         |
| Type of flap           |                  |                             |                               |         |
| DIEP                   | 85 (70.8)        | 29 (76.3)                   | 56 (68.2)                     | 0.319   |
| MS-TRAM                | 35 (29.2)        | 9 (23.7)                    | 26 (31.8)                     |         |
| Neoadjuvant chemotherapy| 49 (40.8)      | 15 (39.5)                   | 34 (41.5)                     | 0.892   |
| History of radiation   | 37 (30.8)        | 17 (44.7)                   | 20 (24.4)                     | 0.031   |
| Adjuvant chemotherapy  | 76 (63.3)        | 26 (68.4)                   | 50 (61.0)                     | 0.32    |
| Adjuvant radiation     | 17 (14.2)        | 5 (13.1)                    | 12 (14.6)                     | 0.627   |
| Immediate reconstruction| 35 (29.2)      | 11 (28.9)                   | 24 (29.3)                     | 0.956   |
| Delayed reconstruction  | 85 (70.8)        | 27 (71.1)                   | 58 (70.7)                     | 0.956   |
| History of abdominal surgery | 17 (14.2) | 5 (13.1) | 12 (14.6) | 0.864 |

### Table 2. Perioperative Fluid Status

|                        | Overall (n = 120) | Flap Complications (n = 38) | No Flap Complications (n = 82) | P       |
|------------------------|------------------|-----------------------------|-------------------------------|---------|
| Intraoperative fluid administration (ml/kg/h) | 7.0 ± 1.2 | 8.7 ± 2.0 | 6.2 ± 1.1 | 0.045 |
| Fluid balance at the end of POD 0 (FB, ml)    | 900 ± 320 | 1100 ± 200 | 820 ± 180 | 0.053 |
| FB/BMI at the end of POD 0                    | 27 ± 10 | 32 ± 9    | 25 ± 7   | 0.083 |
| Positive Delta                                | 28 ± 10 | 29 ± 12   | 27 ± 9   | 0.782 |
| Negative Delta                                | 26 ± 8  | 33 ± 8    | 24 ± 10  | 0.031 |
| UOP at the end of POD 0 (ml/kg/h)             | 1.2 ± 0.3 | 1.7 ± 0.1 | 0.9 ± 0.7 | 0.029 |
compromise and improve salvage rates in the postoperative setting.\textsuperscript{10,11} The impact of perioperative fluid administration on free flap outcomes is also well established across the surgical literature.\textsuperscript{5,8,9,12} Whereas the use of NIRS monitoring as a parameter to predict fluid responsiveness has previously been examined, no such studies have been reported in breast or microvascular reconstruction.\textsuperscript{13} The present work is the first to examine the use of NIRS as a guide to real-time fluid administration in autologous breast flap reconstruction.\textsuperscript{6,7}

In our present study, patients for whom fluid administration was decreased experienced an increase in their tissue perfusion while patients who received a bolus or maintained the same rate of IVF experienced a decrease in their tissue oximetry readings. The use of a fluid restrictive strategy is supported by our previous series which identified improved flap outcomes in patients undergoing a restrictive fluid strategy (<7 ml/kg/h) for the first 24 hours following reconstruction.\textsuperscript{5,8} It is possible that excessive fluid administration results in interstitial tissue edema. This can result in compression of the capillaries and impairment of tissue perfusion. Several retrospective analyses of patients undergoing autologous reconstruction of the head and neck have also found decreased perioperative fluid to be associated with fewer complications and decreased length of stay.\textsuperscript{18,19} It is important to note that underresuscitation has been found to be consequential in the perioperative period as well. In a review of 682 patients undergoing autologous breast reconstruction, Nelson et al.\textsuperscript{9,11} found that intraoperative underresuscitation increased the risk of postoperative flap thrombosis. Although the use of NIRS was not described, the series identified low urine output to be a parameter by which fluid resuscitation can be guided.\textsuperscript{9} The variation in these findings highlights the challenging nature of fluid management in this patient population, and points toward the utility of establishing parameters to tailor fluid management by using a goal directed approach. NIRS utilizes changes in the tissue perfusion and oxygenation status based on absorption of infrared light by hemoglobin chromophores. The resulting measures of differing states of hemoglobin concentrations can accurately detect an abnormality of tissue hemodynamics.\textsuperscript{10,14} Aggressive fluid resuscitation is thought to increase flap edema, causing decreased absorption of infrared hemoglobin chromophores present in the intravascular space. The resulting decrease in T stat readings correlate with local-regional hypoperfusion and in turn may allow NIRS to serve as a parameter by which resuscitation can be guided.

Current data evaluating the use of adjunctive parameters to guide goal directed perioperative fluid management

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\caption{Overall change in tissue perfusion stratified by fluid administration.}
\end{figure}
in breast reconstruction are limited. A prospective pilot study by Funk et al compared traditional parameters such as blood pressure and heart rate to noninvasive cardiac monitoring in patients undergoing mastectomy and microvascular reconstruction. In comparison to the traditional parameters used to assess organ perfusion, goal-directed fluid therapy utilizing an elevated stroke volume variation (>13%) as a trigger for fluid boluses resulted in improved end operative hemodynamics. The authors also noted that the use of a goal directed approach with Vigileo monitoring may have prompted earlier and more timely resuscitation, leading to improved end outcomes. The limitations of the traditional parameters used to assess organ perfusion are also found in the pediatric patient population, where the
use of NIRS has been routinely employed to assess cerebral oxygen saturation. Hilly et al tested the validity of NIRS monitoring as a predictive parameter of fluid responsiveness in infants less than 1 year of age during noncardiac surgery and concluded that NIRS monitoring can be used in conjunction with other clinical parameters to accurately predict and guide fluid responsiveness. Similar findings were noted in a prospective trial evaluating the use of NIRS to predict the need for resuscitation in patients suffering combat casualties. NIRS-derived oxygen saturation obtained early in the course of patient arrival served as a “vital sign” and accurately predicted the need for blood transfusion even when the traditional markers of systemic hypoperfusion were normal. The authors of all the above studies note the limitations of NIRS based on its own inherent parameters, as well as impress the need for more robust data to better stratify the use of NIRS to guide resuscitation.

Our study is not without limitations. A single-center study with retrospective data entails the technical errors and biases as such. NIRS oximetry readings may vary based on positioning and be limited by inaccurate readings. Although we calculated the mean changes at interval periods of and consistently attach our device to the most medial aspect of the skin paddle, variability will inevitably occur. The current analysis focuses on the role of NIRS guided fluid resuscitation in the postoperative-operative period and did not quantify the influence of intraoperative fluid received. It is also important to note that the NIRS oximetry readings represent the oxygen saturation of hemoglobin in that specific area of the flap that the probe was placed on, and do not necessarily reflect the overall oxygen tension for the flap studied. Further studies may evaluate the impact of intraoperative volume on the initial negative ΔTO or positive ΔTO, and the resulting perioperative resuscitation.

In summary, our analysis found that NIRS-derived tissue oxygenation readings may be a noninvasive adjunctive guide in goal directed perioperative fluid management of patients undergoing free tissue breast reconstruction. The lack of robust data indicates the need for future studies.

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