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Predicting complications in immediate microvascular breast reconstruction: Validity of the breast reconstruction assessment (BRA) surgical risk calculator

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Summary *Background:* The Breast Reconstruction Assessment (BRA)-score is a disease-specific risk calculator that estimates the likelihood of postoperative complications in an individual patient. The tool has not been previously externally validated in microvascular breast reconstruction. The purpose of this study was to evaluate the efficacy of the calculator in patients who underwent microvascular reconstruction at a single specialist institution.
Methods: Data from 415 patients who had immediate microvascular breast reconstruction were entered into the calculator. The predicted and observed rates of surgical complications, medical complications, reoperation, and total or partial flap failure were compared. The accuracy of the calculator was assessed using statistical measures of calibration and discrimination.
Results: The calculator accurately predicted the proportion of patients who would experience surgical complications and reoperations but overestimated the rates of medical complications and flap failures. The C-statistics were low for all four prediction models (0.49–0.59), suggesting weak discriminatory power, and the Brier scores were relatively high (0.09–0.44), indicating poor correlation between predicted and actual probability of complications.

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Conclusion: These results suggest that the BRA score cannot accurately identify patients at risk for complications following immediate microvascular breast reconstruction at our institution.

Introduction

It is estimated that one in eight women will be diagnosed with breast cancer in their lifetime. With improvements in multidisciplinary care, increasing numbers of women are surviving the disease, and consequently, there is growing emphasis on quality of life after treatment. Breast reconstruction has been shown to improve body image, self-esteem, and psychosexual wellbeing following mastectomy.[1]

The decision to undergo postmastectomy breast reconstruction (PMBR) is patient driven, and women face a number of choices regarding the nature and timing of reconstruction, which can be overwhelming, especially in the face of a recent cancer diagnosis.[2] In many cases, microvascular autologous breast reconstruction is the technique of choice, as it can provide a large amount of well-vascularized tissue that is similar in appearance and consistency to those of the natural breast.[3] Although microvascular reconstruction has high success rates, it is a more extensive procedure than alloplastic alternatives with potential for relatively high postoperative complication rates, and this can be a major factor in the decision-making process.[4]

Immediate breast reconstruction (IBR) can achieve the most aesthetically pleasing result and perhaps more importantly spares women a period of impaired psychosexual function, as studies show that many women who delay reconstruction experience significant deterioration in well-being following mastectomy.[5] Wider acceptance of the oncological safety of IBR together with increasing public awareness has resulted in greater demand for immediate reconstruction. However, IBR is associated with a higher risk of complications than delayed reconstruction or mastectomy alone.[6] Complications following IBR are particularly significant, as they can delay delivery of essential adjuvant therapies such as chemotherapy and radiation.[7]

Although a number of published studies have provided information on complication rates and risk factors for various PMBR procedures, it can be difficult to translate these population-based data into accurate risk assessment for an individual patient.[4,8-10] Surgeons generally describe average complication rates, which may not be representative of an individual patient's risk. It is particularly challenging for surgeons to evaluate patients who present with multiple risk factors, and currently, they must rely on intuition to estimate the likelihood of adverse outcomes.

Surgical risk calculators consider the cumulative effect of multiple patient and treatment variables on adverse postoperative outcomes. They convert complex statistical models into simplified user-friendly platforms that can generate an accurate estimation of risk based on a patient's unique profile. We have previously evaluated the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) universal surgical risk calculator and found that it lacked the discriminatory power to identify patients at risk for complications after either alloplastic or microvascular breast reconstruction.[11,12] This is at least in part due to the failure of universal calculators to consider variables and outcomes specific to breast reconstruction.

The Breast Reconstruction Assessment (BRA) score is the first publicly available disease-specific risk calculator and was developed exclusively for patients considering immediate PMBR. The (BRA)-score was developed using data from the NSQIP database and validated in the same population using bootstrap analysis.[13] It was subsequently expanded to include procedure-specific outcomes using data from the Tracking Operations and Outcomes for Plastic Surgeons (TOPS) database.[14] The tool was externally validated in implant-based IBR at the developer's own institution.[15] It performed well in the domains of superficial site infection and seroma but failed to accurately predict explantation. However, there has been no previous attempt to validate the model in immediate microvascular reconstruction. In this study, we evaluate the efficacy of the BRA score through external validation in patients undergoing immediate microvascular autologous breast reconstruction at a single specialist center.

Methods

Institutional Research Ethics Board approval was obtained for this study. All patients who underwent immediate microvascular breast reconstruction using an abdominal free flap at the Breast Restoration Program, University Health Network, Toronto, Canada, between January 2009 and May 2018 were eligible for inclusion. Patients were identified from a prospectively maintained institutional database, and patients with complete datasets were included in the study. Data were collected for the 27 fields used in the BRA score surgical risk calculators. They included patient demographics (age, weight, height, and smoking status), comorbidities (American Society of Anesthesiologists Score [ASA], hypertension/antihypertensives, diabetes, clotting disorders, anticoagulation, cardiac procedures, coronary artery disease, peripheral vascular disease, and dyspnea) and treatment factors (previous radiation, planned postmastectomy radiation, previous chemotherapy, and laterality of reconstruction). Data for each patient were entered in the online BRA score calculator, and the predicted risk of surgical complications, medical complications, re-operation, and flap failure (partial or total) was calculated. The observed rates of the four adverse outcomes (within 30 days of surgery) were determined from our institutional database and chart review. All procedures were performed by one of three experienced microsurgeons (AON, TZ, and SOH).

Statistical analyses were performed using R version 3.0.2. *P*-values <0.05 were considered significant. Mean, standard deviation (SD), and range of all continuous variables and frequency of all categorical variables were calculated.

Table 1 Patient demographics and comparison of characteristics of patients who developed complications and those who did not.

	Total $N=415$	Complication $N=119$	No complication $N=296$	*P* value
Mean Age (+/−SD)	50.6 +/− 9.4	52.8 +/− 5.6	49.8 +/− 5.1	0.09
Mean BMI (+/− SD)	29.3 +/− 4.7	32.6 +/− 5.1	29.4 +/− 4.2	0.02[a]
Smoker				
Yes	16	5	11	0.07
No	399	114	285	
Ex-smoker				
Yes	71	26	45	0.31
No	344	93	251	
Radiation				
Yes	150	48	102	0.18
No	265	71	194	
Chemotherapy				
Yes	140	29	111	0.08
No	275	90	185	
Hypertension				
Yes	65	21	44	0.11
No	350	98	252	
Diabetes				
Yes	14	8	6	0.06
No	401	111	290	
Clotting Yes	3	1	2	N/A
Disorder No	412	118	294	
Coronary Yes	4	2	2	N/A
Disease No	411	117	294	
Dyspnea				
Yes	3	2	1	N/A
No	412	117	295	
Bilateral Yes	258	65	193	0.82
Reconstruction No	157	54	103	

[a] Denotes statistical significance. SD = standard deviation. BMI = Body mass index.

The accuracy of the model was assessed using the same statistical measures that were used in the original validation of the calculator.[13] Calibration describes the agreement between the predicted and observed complication rates. It was measured using the Hosmer-Lemeshow (H-L) goodness of fit test with nonsignificant findings (i.e., $p > 0.05$) indicating good agreement between predicted and observed outcomes. Discrimination describes the ability of the model to separate patients who will develop complications from those who will not. It was measured using the concordance (c-) statistic, which is equal to the area under the receiver operator curve for binary data. A value in excess of 0.8 indicates good discriminatory power, while 0.5 indicates the tool is equivalent to random guessing. Finally, the accuracy of the model was assessed using the Brier score, which measures the mean squared difference between predicted and observed outcomes. In an ideal model of prediction, the Brier score approaches 0.

Results

Four hundred fifteen patients underwent immediate breast reconstruction with free deep inferior epigastric artery perforator flaps during the study period (Table 1). The mean age was 50.6 years (SD +/− 9.4, range 24–73 years), and the mean body mass index (BMI) was 29.3 kg/m^2 (SD +/− 4.7, range 19–46 kg/m^2). Sixteen were active smokers in the cohort (3.9%), while 71 were ex-smokers (17.1%). The majority of patients (62%) underwent bilateral reconstructions. One third of patients (33.7%) had previous chemotherapy, while 150 patients (36.1%) had a history of radiation treatment. The commonest comorbidity was hypertension, with 15.7% of patients taking antihypertensive medications. There were 14 patients with diabetes (3.4%) included in the study. The other comorbidities recorded using the calculator (clotting disorder, dyspnea, coronary artery disease, and history of cardiac intervention) were rare, occurring in less than 1% of the study population.

One hundred nineteen patients (28.6%) experienced a complication in the 30-day postoperative period. Patients who developed complications had a significantly higher mean BMI (32.6 +/− 5.1 vs. 29.4 +/− 4.2, $p = 0.02$). There were no other significant differences between the distribution of risk factors recorded using the calculator (Table 1). The accuracy of the calculator was assessed

Table 2 Measure of calibration (Hosmer-Lemeshow, H-L) and discrimination (C-statistic and Brier scores) used in the validation of the four complication models.

	Surgical complication	Medical complication	Re-operation	Total or partial flap failure
Predicted (Mean% +/− SD)	22.8 +/− 5.9	16.9 +/− 10.2	9.5 +/− 2.4	9.4 +/− 4.7
Observed (%)	25.1	1.5	12	2.8
H-L *p*-value	0.82	0.01[a]	0.88	0.03*
C-statistic[b]	0.57	0.49	0.59	0.51
Brier score[c]	0.17	0.44	0.09	0.38

[a] Denotes statistical significance.
[b] C-statistic > 0.8 indicates good discriminatory power while 0.5 indicates random performance.
[c] In an ideal model of prediction, the Brier score approaches 0.

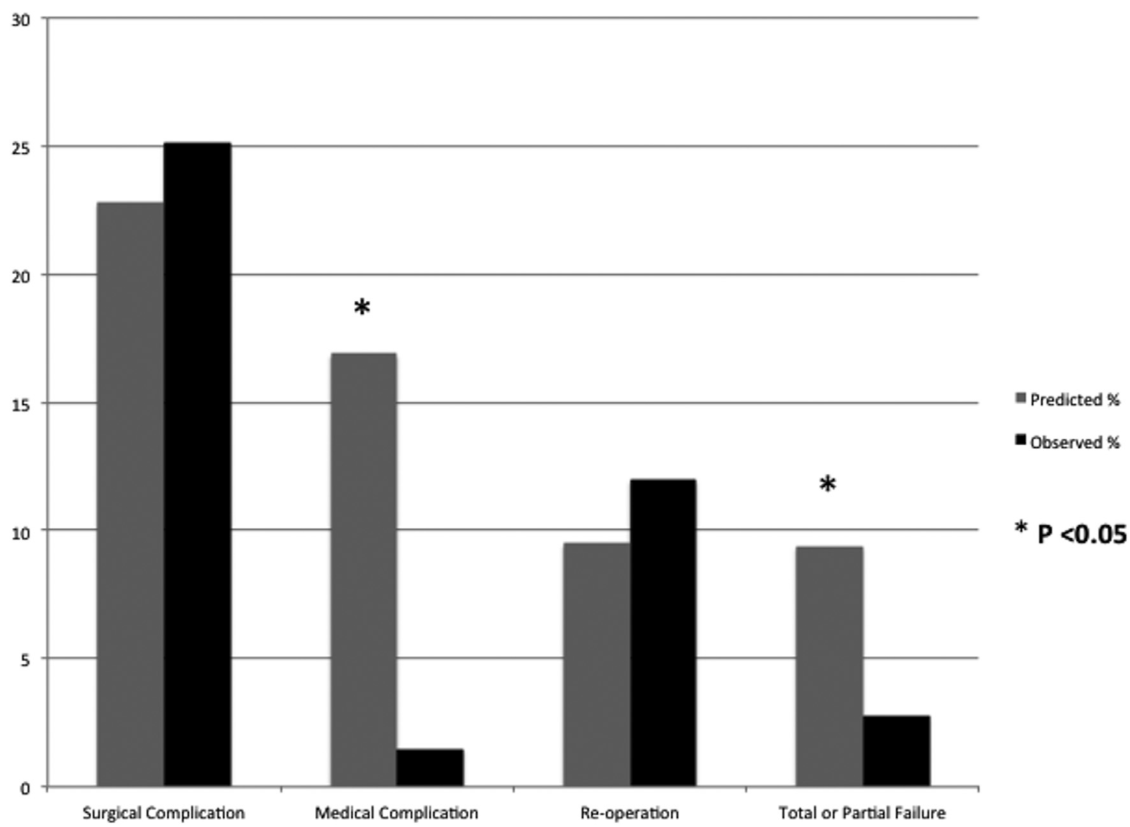

Figure 1 Comparison of predicted and observed complication rates. * Denotes statistical significance on Hosmer-Lemeshow Goodness of Fit test.

for all four outcomes, and the results are summarized in Table 2.

Surgical complications: There was no significant difference between the mean predicted (22.8% +/− 5.9, range 13.1–49.5%) and observed (25.1%) rates of surgical complications in the study (H-L $p = 0.82$, Figure 1). However, the C-statistic was 0.57, indicating that the calculator could not accurately identify patients at risk for surgical complications (Figure 2A). This finding was supported by a relatively high Brier score (0.17).

Medical complications: There was a significant discrepancy between the mean predicted (16.9% +/− 10.2, range 7.7–52.9%) and observed (1.5%) rates of medical complications (H-L $p = 0.01$, Figure 1). The C-statistic (0.49, Figure 2B) and Brier score (0.44) indicated that the calculator could not distinguish patients who were at risk for medical complications from those who were not.

Reoperation: There was no significant difference between the mean predicted (9.5% +/− 2.4, range 5.3–19.9%) and observed (12%) rates of reoperation (H-L $p = 0.88$, Figure 1). However the C-statistic (0.59, Figure 2C) and Brier score (0.09) suggest that the discriminatory power of the calculator was relatively weak and could not identify patients at risk for reoperation.

Total or partial flap loss: The calculator significantly overestimated the rate of total or partial flap failure (mean predicted rate 9.4% +/− 4.7, range 4.6–38.3%, observed rate 2.8%, H-L $p = 0.03$, Figure 1). The C-statistic was 0.51

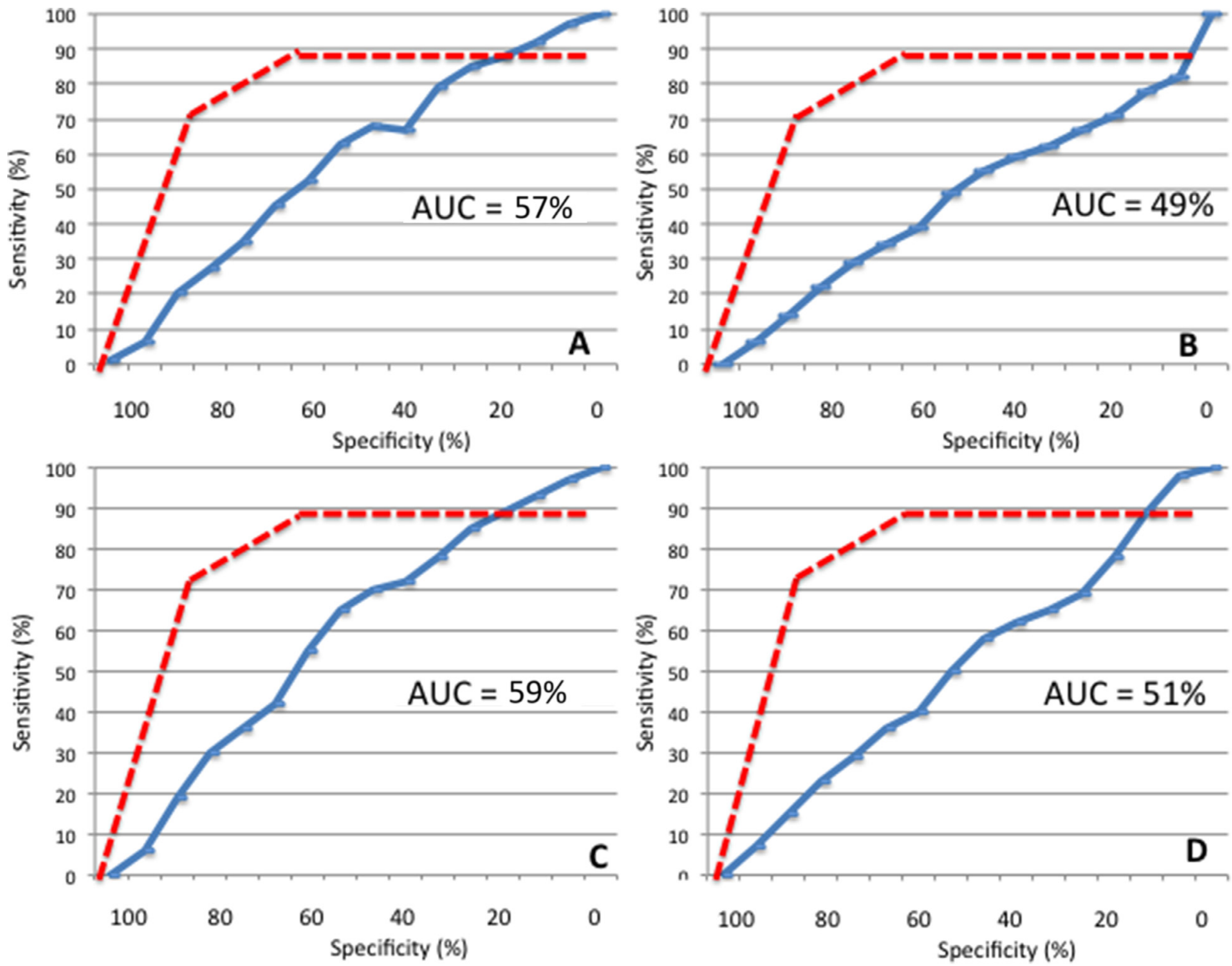

Figure 2 Area under the receiver operator curve (C-statistic) for the prediction models for: (A) surgical complications, (B) medical complications, (C) re-operations, and (D) total or partial flap failure. Dashed lines indicate the ideal model of prediction (C-statistic > 0.9).

(Figure 2D) suggesting the discriminatory power was equivalent to random guessing and the Brier score was high (0.38), indicating the model had a low degree of accuracy in this population.

Discussion

This study demonstrates that the BRA score does not accurately identify patients at risk for complications following microvascular breast reconstruction at our institution. While the calculator accurately predicted the proportion of patients who would have surgical complications and require reoperation, there was a low level of agreement between the predicted and observed rates of medical complications and flap failure. More importantly, the tool failed to discriminate between patients who were at risk for complications and those who were not in all four of the assessed outcome categories. The low C-statistic and high Brier score for each of the complication groups demonstrate that the BRA score has poor discriminatory power and is an ineffective prediction tool in our population. Together, these results indicate that the calculator would not make a useful addition to preoperative consultations at our institution.

Although the BRA score is a procedure-specific tool, many of the included variables are very uncommon in the PMBR population. Patients undergoing PMBR are usually relatively healthy with low rates of major comorbidities. Accordingly, many of recorded variables (bleeding disorders, cardiac surgery, or interventions) were not observed in any patients in our study population and others (clotting disorders, coronary artery disease, and dyspnea), they occurred in <1% of the group. Much of the data are therefore largely irrelevant and unlikely to distinguish patients who will have complications from those who will not. Given the rarity of these variables in patients with PMBR, in general, it would be statistically difficult to demonstrate an association with adverse outcomes. Conversely, other important variables are not considered in the calculator. For instance, although neo-adjuvant therapies have been shown to adversely affect outcomes, the calculator does not determine whether the history of radiation or chemotherapy was recent or remote.[16-18] The calculator considers only immediate breast reconstruction and does not allow patients to compare the complication rates associated with delayed PMBR.

Similarly, the calculator includes only complications that occur within 30 days of surgery and does not necessarily capture outcomes such as fat necrosis or abdominal weakness or bulge.

We have previously identified similar weaknesses in the ACS-NSQIP universal calculator, and as the BRA score was initially developed using the same database, it is perhaps not surprising that the same limitations were observed.[11,12] The NSQIP database collects high-quality prospective data from multiple institutions and plays an essential role in benchmarking and quality improvement. However, the database does not necessarily contain sufficient information to comprehensively analyze predictors of complications for every procedure. This is particularly correct for complex and specialized procedures such as microsurgical reconstruction.[11,19] The BRA score statistical model was based on data from 16,069 immediate breast reconstructions in the NSQIP database; however, less than 5% of these cases were free flaps.[13] Given that over 300 hospitals were contributing data over the 7-year period in question, it is possible that at least some of the data come from low-volume institutions. It has been shown that the experience and caseload of the institution are important determinants of success in microvascular surgery, and hence, the aggregate data in NSQIP may not necessarily represent outcomes at high-volume specialist centers.[20,21]

Like many surgical calculators, the BRA score does not reveal the statistical model; therefore, we cannot ascertain how a particular variable influences the risk score. The relative weighting of some of the variables would, however, seem inconsistent with our clinical observations. Patients with relatively minor medical problems such as hypertension were predicted to have very high rates of postoperative medical complications. For example, a 50-year-old, ASA 3, hypertensive patient with no other comorbidities undergoing bilateral reconstruction is estimated to have 33% risk of medical complications. The calculator overestimated the risk of flap failure in our population. In spite of the relatively high rate of complications, overall failure of microvascular reconstruction is rare. Patients who were active smokers or previous smokers were predicted to have particularly high rates of flap failure. We have previously found that although smokers may have an increased risk of intraoperative microsurgical difficulties, smoking was not an independent predictor of total or partial free flap failure.[22]

We acknowledge the limitations of our study. Although much of the data were gathered prospectively, we did rely on retrospective chart review for details on some complications, which may have affected the accuracy of the data. We did not specifically evaluate the domains of surgical site infection or seroma, as the inclusion criteria for these complications are unclear and retrospective recording may be subject to some subjectivity, especially in minor cases that may have been managed outside our institution. We focused instead on reoperation and flap failures, which are more objective outcomes that are always captured in our data. The calculator does not distinguish between different types of microvascular reconstruction. All the patients in our validation underwent DIEP flap reconstructions, which may have lower complication rates than the rates obtained with other techniques, and this may contribute in part to the inaccuracy of the model in our series.

In spite of its limitations, the BRA score represents an important step toward the development of a risk calculator for breast reconstruction, as it is the first tool to include variables and outcomes of specific interest in PMBR. The calculator is in evolution, and the developers are still making modifications and improvements. It is possible, therefore, that future iterations will provide more accurate predictions. This study demonstrates the importance of statistical validation of surgical risk calculators in specific patient populations prior to their adoption into routine clinical practice, as predictions may not reflect outcomes of microvascular breast reconstruction at individual institutions.

Disclosures

The authors have no conflict of interest.

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