



Presented at the Academic Surgical Congress 2022

## Cost-volume analysis of deep inferior epigastric artery perforator flaps for breast reconstruction in the United States



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### ARTICLE INFO

#### Article history:

Accepted 12 May 2022

Available online 14 June 2022

### ABSTRACT

**Background:** Deep inferior epigastric artery perforator flaps are increasingly utilized over other autologous methods of breast reconstruction. We evaluated the relationship between annual hospital volume and costs after breast reconstruction with the deep inferior epigastric artery perforator flap.

**Methods:** All female patients undergoing elective implant or autologous tissue breast reconstruction were identified using the 2016–2019 Nationwide Readmission Database. Annual hospital volume of deep inferior epigastric artery perforator reconstructions was tabulated and modeled using restricted cubic splines. Institutions were categorized into high- and low-volume based on the inflection point of the spline between annual caseload and costs. The association between high volume status and costs, complications, length of stay, and 30-day nonelective readmission was assessed using multivariable regression.

**Results:** Of an estimated 94,524 patients meeting inclusion criteria, 33,046 (34.6%) underwent deep inferior epigastric artery perforator flap reconstruction. Deep inferior epigastric artery perforator flap utilization increased from 31% in 2016 to 40% in 2019 ( $P < .001$ ) among inpatient breast reconstructions. High-volume hospitals more frequently performed bilateral reconstructions (43.3 vs 37.7%,  $P = .021$ ) but had similar rates of concurrent mastectomy (28.7 vs 30.6%,  $P = .46$ ), relative to low-volume hospitals. The median cost of deep inferior epigastric artery perforator reconstruction was lower (\$29,900 [interquartile range: 22,400–37,400] vs \$31,600 [interquartile range: 22,500–44,900],  $P = .036$ ) at high-volume hospitals compared to low-volume. On adjusted analysis, high-volume status was associated a \$3,800 (95% confidence interval: -6,200 to -1,400) decrement in hospitalization costs, and reduced odds of perioperative complications (adjusted odd ratio: 0.68 95% confidence interval: 0.54–0.86). High-volume status was not associated with length of stay or likelihood of unplanned readmission.

**Conclusion:** The present study demonstrated an inverse cost–volume relationship in deep inferior epigastric artery perforator flap breast reconstruction. In line with goals of value-based health care delivery, our findings may inform referral patterns to suitable centers for deep inferior epigastric artery perforator breast reconstruction.

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### Introduction

Postmastectomy breast reconstruction is a fundamental component of surgical management for breast cancer and has been shown to improve quality of life.<sup>1</sup> Over the past decade, an

This article was accepted for plenary presentation at the 17th Annual Academic Surgical Congress, February 1, 2022.

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<https://doi.org/10.1016/j.surg.2022.05.008>

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increasing proportion of women have opted to undergo autologous tissue reconstruction after mastectomy, in part due to advances in surgical technique and excellent long-term results.<sup>2–4</sup> Compared to implant-based methods, autologous reconstruction has been associated with reduced postoperative complications and health care expenditure while providing improved aesthetics.<sup>4–6</sup> Although various composite tissue donor sites are available, the deep inferior epigastric artery perforator (DIEP) flap has been increasingly utilized and encompasses nearly a third of all autologous breast reconstructions in recent years.<sup>4</sup> Nonetheless, DIEP based reconstruction methods are complex and require specialized perioperative care.

With increasing emphasis on value-based health care delivery for cancer patients in particular, an in-depth examination of post-operative outcomes and cost of widely used complex operations is warranted. After the landmark publication of Birkmeyer et al, a growing body of literature has examined the effect of case volume on clinical outcomes after complex operations.<sup>7</sup> Overall, care at high-volume institutions has been linked to improved clinical outcomes and reduced hospitalization costs across several categories, including microvascular reconstruction for head and neck cancer, repair of aortic aneurysms, pancreatectomy, and pneumonectomy.<sup>8–11</sup> Clinical endpoints aside, strategies to mitigate overall costs of care have become a focal point of value-based health care paradigms. While others have demonstrated a robust association between institutional caseload and costs for many complex microsurgical operations, this relationship remains controversial for DIEP flap breast reconstruction.<sup>12,13</sup>

In the present work, we used a contemporary, nationally representative cohort to examine the association between annual center-level caseload of DIEP flap reconstruction with perioperative complications and inpatient hospitalization costs. We hypothesized that operations performed at high-volume institutions would be associated with reduced costs and improved clinical outcomes, including a reduction in perioperative complications and shorter length of stay.

## Methods

This was a retrospective cohort study of the 2016–2019 Nationwide Readmissions Database (NRD). Maintained by the Agency for Healthcare Research and Quality as part of the Healthcare Cost and Utilization Project (HCUP), the NRD is the largest publicly available all-payer readmissions database in the United States. Using survey weights, the NRD provides robust national estimates, accounting for nearly 60% of US hospitalizations each year. The NRD captures patient and hospital characteristics as well as *International Classification of Diseases, Tenth Revision* (ICD-10) diagnosis and procedure codes from individual state inpatient databases. Unique linkage numbers allow for tracking of readmissions across participating hospitals within each calendar year.

All adult females ( $\geq 18$  years) who underwent elective implant based or autologous tissue breast reconstruction, including deep inferior epigastric perforator (DIEP), transverse rectus abdominis myocutaneous (TRAM), latissimus dorsi (LD), superficial epigastric inferior artery (SIEA), gluteal artery perforator (GAP), and other unspecified autologous flaps, were identified using ICD-10 procedure codes are listed in [Supplementary Table S1](#).<sup>14</sup> Records with missing key data including mortality and costs were excluded (0.76%). Patient and hospital characteristics were defined according to the NRD Data Dictionary<sup>15</sup> and included age, sex, primary insurance payer, hospital bed size, and teaching status. The van Walraven modification of the Elixhauser Comorbidity Index was used to numerically tabulate the burden of chronic conditions.<sup>16</sup> Operative categories of interest included unilateral DIEP reconstruction only, bilateral DIEP only, concurrent mastectomy with unilateral DIEP, and mastectomy with bilateral DIEP reconstruction. To account for operative experience, the annual institutional volume of DIEP reconstructions was tabulated, as previously described.<sup>17</sup>

The primary outcome of interest was index hospitalization costs. Such values were derived by applying center-specific cost-to-charge ratio files to total hospitalization charges and inflation adjusted to the 2019 Personal Health Index. Only hospitalizations entailing DIEP reconstruction were included for cost analysis. With case volume modeled as a restricted cubic spline, a multivariable linear regression was developed to assess the relationship of annual DIEP flap reconstruction volume and hospitalization costs. The

inflection point of the spline was defined as the operative volume at which the second derivative reached zero. This point was used to set the threshold for categorizing hospitals as high (HVH) or low volume (LVH). Several secondary outcomes were also assessed, including perioperative complications, duration of index hospitalization, and unplanned readmission within 30 days of discharge. Perioperative complications included stroke, cardiac, infectious, respiratory, thromboembolic, and procedure-related adverse events as described previously.<sup>8,14</sup>

Categorical variables are reported as proportions, while continuous variables are reported as means with standard deviation (SD) or medians with interquartile ranges (IQR). Cuzick's nonparametric test was used to assess the significance of temporal trends (nptrend).<sup>18</sup> Bivariate comparisons were performed using adjusted Wald and Pearson  $\chi^2$  statistics for continuous and categorical variables, respectively. Multivariable mixed models were developed to assess the independent association between annual DIEP flap reconstruction volume and the aforementioned outcomes of interest. For variable selection, we used the least absolute shrinkage and selection operator (LASSO), an algorithm that reduces overfitting and enhances out-of-sample validity of prediction models.<sup>19</sup> All statistical analyses were performed using Stata 16.1 (StataCorp, College Station, TX). The present study was considered exempt from full review by the Institutional Review Board at the University of California, Los Angeles.

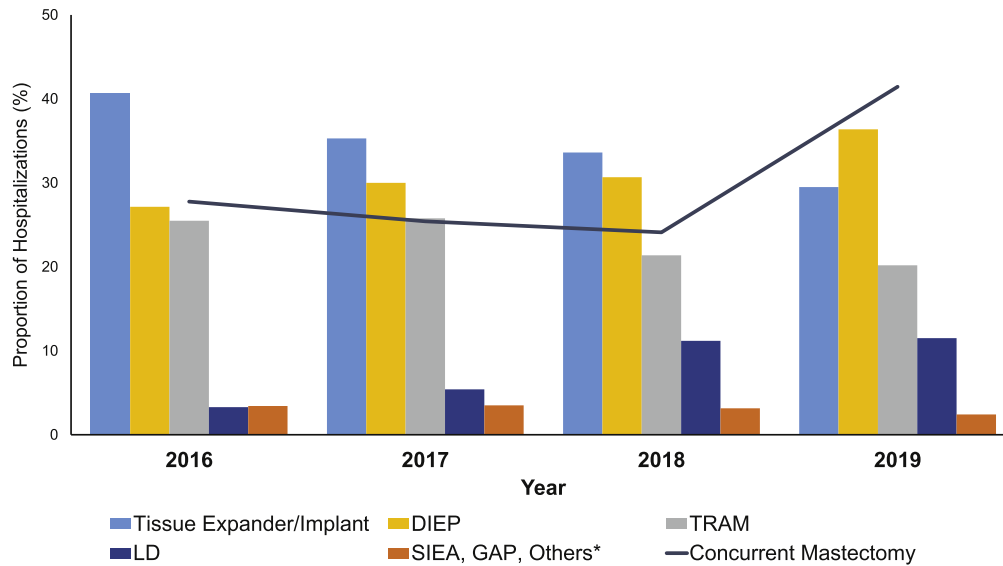
## Results

Of an estimated 94,524 inpatient hospitalizations for elective breast reconstruction, DIEP flaps accounted for 34.6% ( $n = 33,046$ ), while implant-based operations comprised 33.6% ( $n = 31,752$ ). Among the flap types, DIEP accounted for 63.6% of all autologous breast reconstructions. The proportion of implant-based reconstructions as an inpatient decreased over the study period (39.4% in 2016 to 28.5% in 2019, nptrend  $<0.001$ ), while DIEP utilization increased significantly (30.8% in 2016 to 39.7% in 2019, nptrend  $<0.001$ ; [Figure 1](#)). The median costs of isolated DIEP reconstruction increased (\$29,600 [IQR: 22,300–39,600] in 2016 to \$31,500 [IQR: 23,500–43,300] in 2019, nptrend  $<0.001$ ) as well as the costs of concurrent mastectomy with DIEP reconstruction (\$30,000 [IQR: 22,200–41,900] in 2016 to \$32,400 [IQR: 24,600–43,100] in 2019, nptrend  $<0.001$ ).

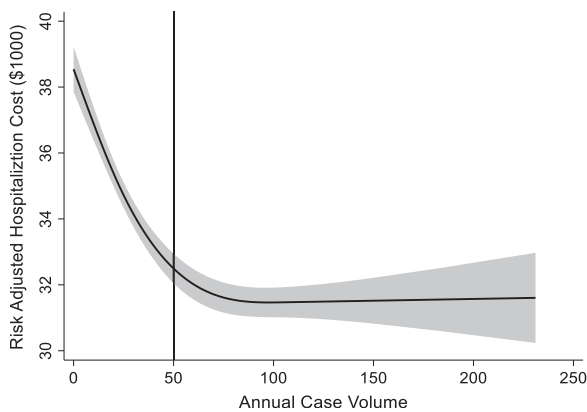
An average of 165 hospitals performed DIEP breast reconstruction each year with an overall annual median caseload of 40 (IQR 18–74). The total number of institutions performing DIEP flap reconstruction increased significantly throughout the study period (144 in 2016 to 202 in 2019, nptrend  $<0.001$ ). Based on restricted cubic spline analysis, HVH was defined as centers that performed at least 50 DIEP flap breast reconstructions per year rendering 11% (19 hospitals/year) of centers as HVH ([Figure 2](#)). Notably, 39.8% of all DIEP flap reconstructions were performed at HVH within the 4-year period. Centers classified as LVH performed a median of 21 (IQR 11–35) DIEP flap reconstructions annually, while HVH had a median caseload of 89 (IQR 66–116).

Overall, HVH more frequently performed isolated bilateral DIEP reconstruction (43.3% vs 37.7%,  $P = .021$ ) and had comparable rate of single-stage reconstruction, compared to LVH ([Table 1](#)). Patients treated at HVH and LVH were similar in age (51.5 years  $\pm$  9.6 vs 51.1  $\pm$  9.6,  $P = .17$ ) and distribution of the Elixhauser Comorbidity Index (1 [0–2] vs 1 [1–2],  $P = .12$ ). Compared to their counterparts at LVH, patients undergoing DIEP flap reconstruction at HVH more frequently had private insurance (79.5% vs 76.5%,  $P = .003$ ).

A bivariate comparison of clinical outcomes is shown in [Supplementary Table S2](#). Patients treated at HVH incurred lower inflation-adjusted costs (\$29,900 [IQR: 22,400–37,400] vs \$31,600



**Figure 1.** Annual number of breast reconstructions stratified by type and proportion of concurrent mastectomy performed at the time of reconstruction. DIEP, deep inferior epigastric perforator; GAP, gluteal artery perforator; LD, Latissimus dorsi; SIEA, superior inferior epigastric artery; TRAM, transverse rectus abdominus myocutaneous.



**Figure 2.** Risk-adjusted spline analysis demonstrating cost–volume relationship for deep inferior epigastric perforator flap reconstruction with inflection point at 50 cases per year.

[IQR: 22,500–44,900],  $P = .036$ ) while having lower incidence of overall complications (5.4% vs 7.8%,  $P < .001$ ) and shorter length of stay (3 days [3–4] vs 4 [3–5],  $P < .001$ ). Rates of unplanned 30-day readmissions, however, were similar between the 2 groups (4.2% vs 4.8%,  $P = .13$ ). After multivariable adjustment with LVH as reference, HVH status was associated with a decrement in costs ( $\beta$ : -\$3,800 95% CI: -6,200 to -1,400,  $P = .002$ ) as well as lower odds of developing respiratory, infectious, and venous thromboembolic complications (Figure 3). Of note, HVH status was not associated with altered odds of procedure-related complications (Figure 4). Among other factors, bilateral DIEP operation alone ( $\beta$ : +\$4,200, 95% CI: 3,000–5,300,  $P < .001$ ) and bilateral DIEP with mastectomy ( $\beta$ : +\$4,800, 95% CI: 3,100–6,500,  $P < .001$ ) were associated with increased costs (Table II). In the presence of at least 1 perioperative complication, HVH status remained associated with a significant reduction in costs ( $\beta$ : -\$14,800 95% CI: -22,100 to -7,400,  $P < .001$ ) and length of stay ( $\beta$ : -1.8 days 95% CI: -2.8 to -0.7,  $P = .001$ ), with LVH as reference.

## Discussion

Notwithstanding outpatient procedures, we found DIEP flaps to account for more than 50% of all autologous tissue breast

reconstructions requiring hospitalization in the United States. Over the 4-year study period, we observed a significant increase in the number of DIEP flap breast reconstructions performed. With a volume threshold of 50 cases/year, operations at high-volume hospitals were associated with significantly reduced inpatient hospitalization costs. In addition, high-volume hospitals were linked to lower odds of systemic complications as well as shorter length of stay. Several of our findings warrant further discussion.

The inpatient utilization of DIEP flaps rose from 31% to 40% of all breast reconstructions between 2016 and 2019. In congruence with our findings, the American Society of Plastic Surgeons reported a 250% relative increase in DIEP case volume from 2018 to 2020.<sup>20,21</sup> Using NRD, we observed a 40% increase in the number of institutions performing DIEP flap reconstructions during the same period. Interestingly, we further observed a significant increase in single-stage mastectomy and DIEP reconstruction in conjunction with a decrease in single-stage implant-based reconstruction. Previously, Panchal et al described high failure rates associated with postreconstruction radiation therapy in implant recipients may influence surgeons and patients alike to favor autologous methods.<sup>22</sup> Of the various methods of autologous reconstruction, prior studies have shown DIEP flaps to demonstrate superior aesthetic results, high patient satisfaction, and low complication rates.<sup>23,24</sup> Given the sharp increase in utilization of this complex form of breast reconstruction, efforts to identify drivers of hospitalization costs are warranted in the context of delivering value-based health care.

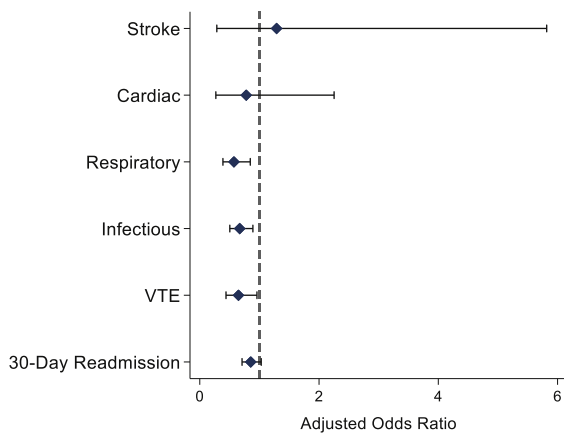
In the present cross-sectional study, we noted overall hospitalization costs to be lower at centers performing a high volume of DIEP reconstructions. In contrast, Billig et al demonstrated an increase in health care costs with rising center-level reconstruction volume.<sup>13</sup> However, Billig used arbitrary volume thresholds and hypothesized a linear relationship between hospital volume and expenditures.<sup>13</sup> To better depict the functional relationship between hospital volume and costs, we modeled annual operative volume using restricted cubic splines and identified an inflection point at 50 institutional cases per year. Using this cutoff, high-volume centers were associated with a \$4,000 decrement in costs. In congruence with our findings, Reid et al found increasing volume of all microsurgical breast reconstruction cases to be linked to lower costs.<sup>25</sup> The cost-effectiveness of complex operations at high-volume centers is likely due to more efficient

**Table 1**

Bivariate comparison of patient, operative, and hospital characteristics stratified by annual hospital volume of DIEP flap reconstruction

	Overall (n = 33,046)	HVH (n = 13,141)	LVH (n = 19,905)	P value
Age (y ± SD)	51.2 ± 9.6	51.5 ± 9.6	51.1 ± 9.6	.08
Elixhauser Index (median, IQR)	1 [1-2]	1 [0-2]	1 [1-2]	.12
Operative characteristics (%)				
Unilateral DIEP only	34.0	30.8	36.1	.005
Bilateral DIEP only	39.9	43.3	37.7	.021
With concurrent mastectomy				
Unilateral DIEP	9.5	9.1	9.8	.42
Bilateral DIEP	16.6	16.8	16.4	.80
Insurance coverage (%)				
Medicare	10.4	10.6	10.4	.003
Medicaid	8.1	6.7	9.3	
Private	77.9	79.5	76.5	
Other	3.6	3.2	3.8	
Income quartile (%)				
0–25	15.1	12.2	16.9	.001
25–50	19.8	17.8	21.1	
50–75	27.3	26.6	27.8	
75–100	37.8	43.4	34.1	
Hospital characteristics (%)				
Teaching status				
Rural, nonteaching	0.1	0.0	0.3	<.001
Urban, nonteaching	10.1	2.8	19.1	
Urban, teaching	89.8	97.2	80.6	
Location				
Large metropolitan	80.1	87.6	76.4	.042
Small metropolitan	19.1	12.4	23.5	
Micropolitan	<0.1	0.0	0.1	

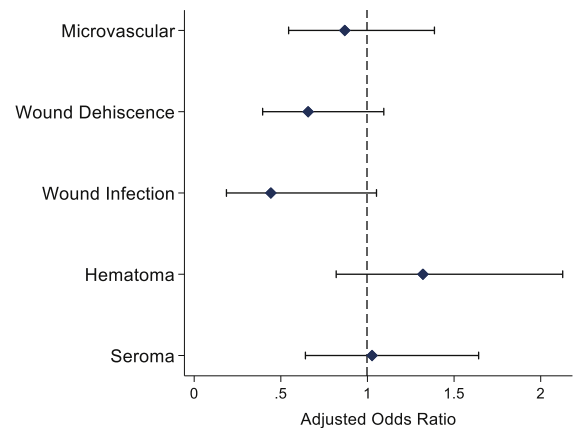
DIEP, deep inferior epigastric perforator; HVH, high-volume hospitals; IQR, interquartile range; LVH, low-volume hospitals; SD, standard deviation.



**Figure 3.** Adjusted odds ratios of systemic complications in patients treated at high-volume hospitals. Reference: low-volume hospitals. 30-day readmission reported as unplanned readmission within 30 days of discharge. VTE, venous thromboembolism.

intraoperative and postoperative care pathways established in experienced centers. Our findings may be particularly relevant in referral decisions and pay for performance paradigms. Referral of DIEP candidates to high-volume centers may be financially advantageous for insurers and result in an overall reduction in costs of care at a large scale.

Although the relationship between high volume and improved outcomes is well documented in the existing literature, examination of this association among DIEP flap reconstructions remains limited.<sup>12,13,25</sup> In the present work, high procedural volume was associated with reduced rates of systemic complications, such as respiratory, infectious, and thrombotic events. However, we did not observe a significant association between center volume and procedural complications. Because surgical site problems can present



**Figure 4.** Risk-adjusted odds ratios of procedure-related complications association of high-volume status. Reference: low-volume hospitals.

in a delayed fashion, our analysis of in-hospital events may only have captured a small proportion. Furthermore, procedure-related complications may be related to surgeon expertise, which, in a super-specialized field such as microsurgery, may be relatively homogenous between high-volume and low-volume hospitals. Although postoperative complications are considered major drivers of resource utilization,<sup>26</sup> the cost savings effect of high-volume status remained even among those who developed at least 1 undesired outcome. High-performing centers may be better equipped with a broader range of resources and experienced teams to deliver streamlined care and may better deal with postoperative problems as they develop.

The present study has several important limitations inherent to its retrospective design and administrative nature. While regional variations in cost may exist, the NRD does not provide hospital

**Table II**  
Multivariable regression model demonstrating factors associated with hospitalization costs

	B-Coefficient (\$1,000)	95% CI	P value
Year	0.6	-0.5, 1.8	.26
Age	0.0	-0.1, 0	.014
Elixhauser comorbidity index	0.4	-0.1, 0.8	.10
Operative characteristics			
Unilateral DIEP only	Ref.		
Bilateral DIEP only	4.2	3.0, 5.3	<.001
With concurrent mastectomy			
Unilateral DIEP	0.9	0.5, 2.4	.22
Bilateral DIEP	4.8	3.1, 6.5	<.001
Payer status			
Private insurance	Ref.		
Medicare	-0.9	-2.0, 0.2	.11
Medicaid	-0.2	-1.8, 1.4	.79
Other	1.0	1.1, 3.2	.35
Comorbidities			
Congestive heart failure	0.4	-3.1, 3.9	.83
Coronary artery disease	-1.7	-4.2, 0.8	.19
Arrhythmia	2.8	1.3, 4.3	<.001
Chronic neurologic conditions	2.2	-0.8, 2.8	.15
Chronic lung disease	1.8	0.8, 2.8	<.001
Hypothyroidism	0.4	-0.6, 1.5	0.42
Renal disease	9.3	5.4, 13.2	<.001
Liver disease	4.4	1.5, 7.3	.003
Coagulopathy	5.2	2.5, 7.9	<.001
Electrolyte disturbances	3.4	1.2, 5.5	.002
Hospital characteristics			
High-volume status	-3.8	-6.2, -1.4	.002
Teaching status			
Nonmetropolitan	Ref.		
Metropolitan nonteaching	3.9	0.2, 7.6	.040
Metropolitan teaching	-1.3	-3.8, 1.2	.31

CI, confidence interval; DIEP, deep inferior epigastric perforator; Ref., reference.

location, thereby limiting our analysis. Furthermore, the NRD lacks clinically relevant data that may affect cost such as specialized imaging studies and laboratory workup. In addition, the timing and exact nature of perioperative events such as complications and intensive care unit admission could not be ascertained. Other factors such as individual surgeon experience and long-term flap outcomes could not be assessed. Importantly, the NRD does not capture outpatient or short-stay procedures (<24 hours), resulting in underestimation of outpatient volume for reconstruction. Nonetheless, we performed a cost-volume analysis among patients undergoing DIEP flap reconstruction using robust statistical methods in the largest, nationally representative readmissions database in the United States.

In conclusion, we found institutional operative volume to be inversely related to hospitalization costs for DIEP breast reconstruction. Given the concomitant reduction in complications with increasing center volume, our results suggest referral to expert centers to be both clinically and financially advantageous.

#### Funding/Support

None declared.

#### Conflict of interest/Disclosures

We have no disclosures.

#### Supplementary materials

Supplementary materials associated with this article can be found in the online version <https://doi.org/10.1016/j.surg.2022.05.008>.

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