Surgery 166 (2019) 867–872

Contents lists available at ScienceDirect

Surgery

journal homepage: www.elsevier.com/locate/surg

Presented at the Academic Surgical Congress 2019

Hospital factors strongly influence robotic use in general surgery

Camille L. Stewart, MD[a], Sinziana Dumitra, MD[a], Carolijn Nota, MD[a], Philip H.G. Ituarte, PhD[a], Laleh G. Melstrom, MD, MSc[a], Yanghee Woo, MD[a], Gagandeep Singh, MD[a], Yuman Fong, MD[a], Hari Nathan, MD, PhD[b], Susanne G. Warner, MD[a,*]

[a] Department of Surgery, City of Hope, Duarte, CA
[b] Department of Surgery, University of Michigan, Ann Arbor, MI

ARTICLE INFO

Article history:
Accepted 4 May 2019
Available online 14 June 2019

ABSTRACT

Background: We hypothesized that general surgeons are more likely to use a robotic surgical platform at hospitals where more urologic and gynecologic robotic operations are performed, suggesting that hospital-related factors are important for choice of usage of minimally invasive platforms.

Methods: We queried the National Inpatient Sample from 2010 to 2014 for patients who underwent stomach, gallbladder, pancreas, spleen, colon and rectum, or hernia (general surgery), prostate or kidney (urologic surgery), and ovarian or uterine surgery (gynecologic surgery). Hospitals were grouped into quartiles according to percent volume of robotic urologic or gynecologic operations. Multivariable logistic regression modeling determined independent variables associated with robotics.

Results: Survey-weighted results represented 482,227 open, 240,360 laparoscopic, and 42,177 robotic general surgical operations at 3,933 hospitals. Robotics use increased with each year studied and was more likely to be performed on younger men with private insurance. The odds of a general surgery patient receiving a robotic operation increased with urologic and gynecologic use at the hospital. Patients at top quartile hospitals for robotic urologic surgery had 1.34 times greater odds of receiving robotic general surgery operations (confidence interval 1.15–1.57, $P < .001$) and 1.53 times greater odds (confidence interval 1.32–1.79, $P < .001$) at top quartile robotic gynecologic hospitals. These findings were independent of study year, surgical site, insurance type, and hospital type and persisted when only comparing laparoscopic to robotic procedures.

Conclusion: Use of robotics in general surgery is independently associated with use in urologic and gynecologic surgery at a hospital, suggesting that institutional factors are important drivers of use when considering laparoscopy versus robotics in general surgery.

Introduction

Minimally invasive surgery is used widely across many different surgical disciplines and has been associated with decreased duration of hospital stay, perioperative morbidity, and overall cost for many procedures.[1–4] The transition away from open surgery began with traditional laparoscopy using straight instruments manipulated extracorporally by the surgeon. The surgical robot was introduced as an additional tool to augment laparoscopic practice. Advantages of robotic surgery include a 3-dimensional view, wristed motion, improved surgeon ergonomics, and faster learning, along with faster learning curve and retention of operating skills.[5,6] These advantages are counterbalanced by greater equipment costs and in many cases greater operative times, lack of haptic feedback, and the requirement of an additional trained bedside assistant.

Adoption patterns of minimally invasive surgery and specifically robotic surgery vary by field and procedure. For example, laparoscopic prostate surgery was found to be technically difficult and thus was implemented slowly. When approached robotically, the learning curve was decreased and is now the standard of care in developed countries for many genitourinary (GU) specialists.[7,8] Minimally invasive gynecologic (GYN) surgery has seen

Research reported in this publication was in part supported by the National Cancer Institute of the National Institutes of Health under award number NIH 5K12CA001727-20.

Drs Stewart and Woo report receiving professional honoraria from Verb Surgical.

* Reprint requests: Susanne G. Warner, MD, Department of Surgery, City of Hope, 1500 East Duarte Road, MOB 1002B, Duarte, CA 91010.
E-mail address: suwarner@coh.org (S.G. Warner).

https://doi.org/10.1016/j.surg.2019.05.008
0039-6060/

fluctuating trends, but robotics platforms remain used heavily.[9] As such, the majority of the robotic cases performed in the United States are GU or GYN procedures.[10,11] Within abdominal general surgery, however, robotic adoption has been slower and varies more widely by surgical site.[12–14] Reasons for this are unclear. Comfort with traditional laparoscopy, combined with a greater cost of the robot, increased operative times, and difficulty operating in multiple abdominal quadrants could influence adoption of this technology. There is, however, little information available about precise patient and hospital characteristics influencing adoption of robotic general surgery techniques, specifically as it relates to the use of robotics in other abdominal surgical specialties. We hypothesized that general surgeons would be more likely to use a robotic surgical platform at hospitals where more urologic and gynecologic robotic operations were performed and that this would be independent of other patient or hospital specific variables.

Materials and Methods

Dataset

Data for this study were obtained from the National Inpatient Sample (NIS), Healthcare Cost and Utilization Project (HCUP), and the Agency for Healthcare Research and Quality for the years 2010 to 2014.[15,16] The NIS is a database of hospital inpatient discharges representing 97% of the US population. It is an administrative dataset that is compliant with the Health Insurance Portability and Accountability Act of 1996 and includes publicly available, de-identified all-payer claims on all diagnoses and procedures performed during admission and captured via the *International Clinical Diagnoses*, Ninth Revision (ICD-9) codes. The specified date range was chosen because the 17.4 series of ICD-9 codes delineating robot-assisted procedures emerged in the latter half of 2008. Using NIS data for the years 2008 and 2009 to review monthly changes in frequency of robot-assisted prostate operations, we confirmed empirically that application of the 17.4 series was widespread and common by the end of 2009. Of note, before 2012, NIS data represented all records from each hospital selected, but starting in 2012, NIS used a random sample of discharges from all hospitals participating in HCUP. According to HCUP, these changes to the sampling strategy produce more precise estimates of trends in the US population level (HCUP).[15,16] To account for this change HCUP has suggested survey weighting for years before 2012. These have been used as detailed below.

Study population

Adult patients undergoing inpatient, elective surgical procedures were identified using ICD-9 procedure codes (Supplemental Table I). Principal procedure codes were used to categorize procedures as general surgery (GS), GU, or GYN. GS procedures included operations involving the stomach, gallbladder, pancreas, spleen, colon and rectum, or hernia. GU procedures included prostate and kidney resections. GYN procedures included resections of the uterus and ovaries. Within each of these groups, procedures were then categorized as open, laparoscopic, or robotic. Procedures were coded as open if procedure descriptions omitted laparoscopy, and if laparoscopic or robotic codes were absent from all secondary procedures. Procedures were coded as laparoscopic if the principal procedure description was laparoscopic, if any principal procedure code was paired with 1 of 2 laparoscopic secondary procedure codes (54.21, 54.51), and if robotic codes were absent from all secondary procedures. Procedures were coded as robotic if a robotic code (17.4) ever appeared as a secondary procedure. For each year, only general surgery patients treated at hospitals with at least 1 robotic procedure (either GS, GU, or GYN) were included to eliminate hospitals without a robotic platform from skewing data.

Additional patient demographics were queried from the database, including sex, age, race and ethnicity, insurance payer, median household income of the patient's residence zip code, and comorbidities. Comorbidity scores were calculated using the Deyo modification of the Charlson comorbidity index.[17,18] Hospital characteristics were also queried, including hospital location, teaching status, and size. In NIS, a single variable represents both hospital location and teaching status categorized as rural, urban, or urban-teaching; hospital size is based on number of beds.

Data analysis

For each year studied, the total number of all GU or GYN operations was determined for each hospital. The number of either GU or GYN robotic operations was also measured. For each hospital, the percentages of robotic procedures were then divided into quartiles calculated separately for GU or GYN. For GU, the quartiles were 0%–31.25%, >31.25%–52.0%, >52.0%–69.2%, and >69.2%. For GYN the quartiles were 0%–6.25%, >6.25%–14.2%, >14.2%–26.95%, and >26.95%. These values were selected to create hospital groups with high, high–moderate, moderate, and low robotic utilization in GU and GYN surgery while maintaining an adequate number of patients within each group. Each year of NIS, data were trend-weighted so that results would be representative of national trends. As instructed by HCUP, updated trend weights were added to NIS data for the years 2010 and 2011 in order to produce estimates of frequencies comparable to estimates based on the redesigned sampling strategy enacted in 2012. Comparisons based on patient, surgical approach, and hospital types were then made with Pearson χ^2 analysis, univariate logistic regression, and multivariable logistic regression. All analyses were performed using Stata software, version 14.0 (StataCorp LP, College Station, TX).

Results

Patient and operative characteristics

Trend-weighed data represent 2,154,428 patients who met study criteria; 43% underwent a stomach, gallbladder, pancreas, spleen, colon and rectum, or hernia operation (general surgery, GS); 38% underwent resection of the uterus or ovaries (gynecologic, GYN); and 19% underwent a prostate or kidney resection (genitourinary, GU). These patients underwent operative care at 3,933 hospitals. Of note, there were 1,817 hospitals excluded because they did not treat general surgery patients with at least 1 robotic procedure performed in either GS, GU, or GYN. The percentage of hospitals without any robotic procedures for the year decreased annually from 56.0% in 2010 down to 39.8% in 2014. Demographics and hospital factors are included in Table I. Demographics including age, comorbidities, race, neighborhood income, and insurance status were different based on surgical specialty. Differences were also observed for hospital types (urban teaching status) and operative approach (open, laparoscopic, or robotic). From 2010 to 2014, the number of robotic operations increased steadily for GS and GU but decreased for GYN (Fig1, *A*). The increased use of robotic surgery observed each year in general surgery was also observed for each surgical site within general surgery (Fig 1, *B*).

Patient and hospital features associated with robotic surgery

Multivariable regression analyses were performed using the above variables with 3 different models: robotic surgery versus all other operative modalities, minimally invasive (robotic and

Table I
Demographics of GS, GYN, and GU patients having elective inpatient procedures

	GS (n = 933,939)	GYN (n = 808,618)	GU (n = 411,871)	*P* value
Age (mean, SE)	60.5 (0.1)	49.5 (0.1)	60.5 (0.1)	<.001
Female, %	55.5	100	19.2	<.001
Comorbidities, none, %	44.1	67.0	11.6	<.001
Zip code household income highest quartile, %	26.2	27.2	28.1	.03
White, %	73.3	57.9	70.6	<.001
Privately insured, %	44.8	66.8	53.8	<.001
Urban teaching, % Hospital	69.4	66.7	74.4	<.001
Large hospital, %	69.3	69.7	70.2	.75
Operative approach				<.001
Open	51.3	64.7	38.1	
Laparoscopic	44.2	16.2	5.5	
Robotic	4.5	19.1	56.4	
Increase in robotic cases 2010–2014, %	461	122	88	<.001

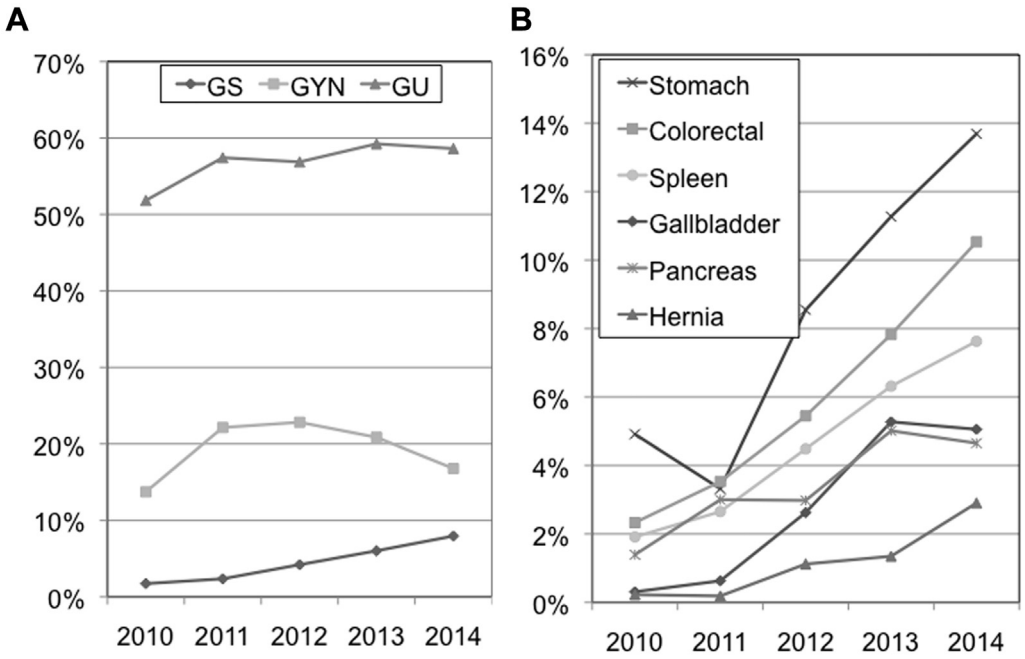

Fig 1. Frequency of inpatient elective robotic surgeries performed annually by surgical specialty (*A*) and by surgical site within general surgery (*B*).

laparoscopic) versus open surgery, and robotic versus laparoscopic surgery alone. This approach was used to compare the influence of patient and hospital characteristics on minimally invasive surgery overall and also specifically on robotic surgery. Results are reported in Table II. When robotic surgery was compared with open and laparoscopic surgery combined, robotic surgery was more likely to be performed on patients who were men with private insurance undergoing colorectal surgery and having the operation performed in a small or medium sized hospital. When minimally invasive surgery (robotic plus laparoscopic) was compared to open surgery, additional factors became statistically significant; minimally invasive surgery was more likely to be performed on patients without comorbidities and those who lived in wealthier neighborhoods. In contrast, when robotic surgery was only compared with laparoscopic surgery we found that race, insurance status, and neighborhood wealth were no longer statistically significant factors. To assess more comprehensively the relationship of surgical subspecialty to GS robot utilization, we focused further on GU and GYN by dividing hospitals into quartiles based on GU and GYN robot use as described earlier.

The use of robotics within GS was strongly and independently correlated with the use of robotics for GU and GYN procedures at the hospital in all 3 models. As the frequency of robotic surgery in GU and GYN specialties increased, so did the frequency of robotics in GS. This increase became statistically significant for hospitals that were in the highest quartile of robotic use in GU and GYN procedures (Table II, Fig 2). When only minimally invasive surgical patients were compared, GS patients treated at hospitals in which >69.2% of GU procedures were performed robotically were 1.33 times (95% confidence interval [CI], 1.13–1.56) more likely to undergo a robotic operation themselves ($P < .001$). Likewise, GS patients treated at hospitals in which >26.95% of GYN procedures were performed robotically were 1.49 (95% CI 1.27–1.73) more likely to have a robotic operation themselves ($P < .001$). We found 9.6% of highest quartile hospitals overlapped for the highest quartile GU and GYN institutions. GS patients treated at hospitals that were both highest quartile for GU and GYN robotic procedures were 1.55 (95% CI 1.20–1.99) more likely to have a robotic operation ($P = .001$). These findings were independent of other patient and hospital variables that might influence the decision for robotic use.

Table II
Multivariable regression analysis for factors associated with robotic use in elective inpatient general surgery

	Multivariable OR robot vs all others	Multivariable OR MIS vs open	Multivariable OR robot vs Lap
Age	0.99 (0.99–0.99)	0.99 (0.99–0.99)	0.99 (0.99–0.99)
Female	0.94 (0.89–0.98)	1.08 (1.06–1.10)	0.91 (0.87–0.96)
Comorbidities, none	0.97 (0.92–1.03)	1.40 (1.37–1.44)	0.81 (0.76–0.86)
Procedural site, colon/rectum	2.35 (2.10–2.63)	0.38 (0.35–0.41)	3.40 (3.03–3.83)
Race, white	0.99 (0.90–1.09)	1.06 (1.02–1.10)	0.96 (0.87–1.05)
Insurance, private	1.11 (1.05–1.17)	1.16 (1.13–1.19)	1.03 (0.97–1.10)
Zip code household income highest quartile	1.02 (0.94–1.11)	1.20 (1.15–1.25)	0.92 (0.84–1.01)
Urban teaching hospital	0.89 (0.68–1.14)	1.14 (0.99–1.31)	0.77 (0.59–1.01)
Large hospital	0.83 (0.73–0.93)	0.93 (0.88–0.99)	0.83 (0.73–0.94)
Hospital highest quartile GU robot	1.34 (1.15–1.57)	1.09 (1.01–1.17)	1.33 (1.13–1.56)
Hospital highest quartile GYN robot	1.53 (1.32–1.79)	1.16 (1.08–1.26)	1.49 (1.27–1.73)
Hospital highest quartile GU and GYN robot	1.55 (1.21–1.98)	1.10 (0.99–1.24)	1.55 (1.20–1.99)

Odds ratio >1 indicates greater likelihood for robotic or MIS. For procedure site, gallbladder is the reference group.
MIS, minimally invasive surgery.

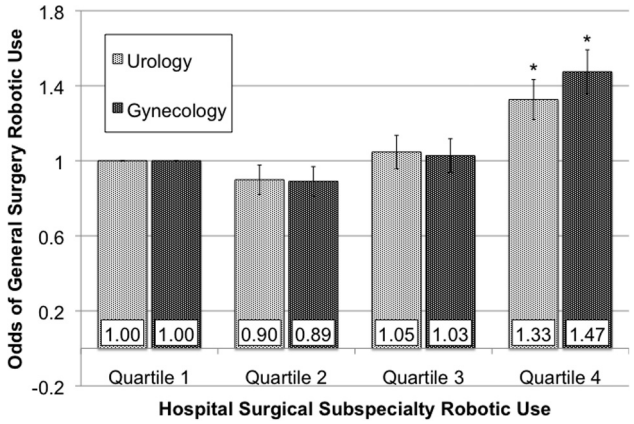

Fig 2. Odds of robotic use in elective inpatient general surgical procedures at a hospital versus the frequency quartile of robotic use in gynecology and urology procedures at the hospital. Robotic use is more likely in general surgery at hospitals in the highest quartile for robotic use in gynecologic and urologic surgeries.

Discussion

In this study, we examined the use of robotics for inpatient general surgical procedures involving the colon, spleen, stomach, pancreas, and gallbladder, and hernias, from 2010 to 2014 using the database of the National Inpatient Sample. The procedures were chosen with the intent of exploring areas where minimally invasive surgery is the accepted standard of care. We observed that robotic use increased annually and asked which patient and hospital features contributed most to this increase. We found that patient-specific variables, such as sex, comorbidities, and surgical site played a role. These findings were expected because similar trends have been identified in the colorectal and urology literature.[19,20] Hospital features also were strongly associated with adoption of robotics in general surgery; small and medium sized hospitals and nonteaching hospitals performed more robotic general surgery. We anticipated patient-based disparities that have been identified by other authors. The novel finding in this study was that robotic use within general surgery was associated with greater robotic use in GU and GYN operations at the same hospital, and that this was independent of factors that were patient-specific and hospital-specific in multivariable analysis. This was true when comparing robotic surgery to traditional laparoscopy and open surgery and when comparing robotic surgery to traditional laparoscopy alone. These findings were found despite the considerably different patient populations treated by the three different surgery specialties. In fact, features that drove the use of minimally invasive surgery, such as race and insurance status, were no longer statistically significant when comparing robotic to laparoscopic surgery. These results imply that when there is a choice between a robotic and the traditional laparoscopic approach for inpatient general surgery, institutional factors may be more important. In other words, robotic surgery is not just used where most appropriate or only with patients of higher socioeconomic strata, but its use seems also to be used most often at hospital locations with the greatest buy-in to the technology. To our knowledge, these relationships have not been examine previously outside of industry data.

The concept of robotic use being driven by nonclinical factors has been discussed in the past. There are no conclusive clinical studies within general surgery showing that robotic surgery is better than or even non-inferior to traditional laparoscopy, but there is considerable evidence that use of the robot increases cost.[21–23] Barbash et al demonstrated that market forces were primary drivers in hospital acquisition of surgical robots and that robot acquisition led to regional increases in prostatectomies.[24] Wright et al also showed correlation between competition in the hospital market and use of robotic surgery for GU and GYN procedures.[25] It stands to reason that similar market forces and competition would drive adoption of robotic general surgery as well. Because smaller and nonteaching hospitals must work harder to attract patients, these market forces may explain our finding that more robotic general surgery is being performed at smaller and nonteaching hospitals.[26,27] Similar nonclinical factors may also account for why we saw an association of increased use of the robot in general surgery at high volume robotic gynecology centers, despite the decreasing use of robotics in gynecology starting in 2012. The Society of Gynecologic Surgeons in combination with the American College of Obstetricians and Gynecologists have published several committee opinions regarding robotic use, which can be viewed as unfavorable. These statements assert that robot-related complications are underreported and recommend that new technology should be specifically addressed with patients.[28,29] Our findings could be interpreted as the following: high volume robotic gynecology centers have external pressure to the use the robot despite national trends of decreasing use and that this pressure is exerted across specialties at a hospital.

Having a robotic program requires substantial upfront investment from the institution and surgeons and operating room staff, which affects all surgical subspecialties. Thus, it is also possible that hospitals with robots used for GYN and GU procedures would encourage general surgery use to defray the costs of system upkeep. Furthermore, robotic surgery can proceed more easily at hospitals where experienced robotic teams already exist in the operating

room. There is inherent increased efficiency with teams who are familiar with equipment and follow predefined processes.[30] This concept is especially true with regard to robotic technology because these dedicated teams can assist surgeons navigating the initial robotic learning curve.[31] When surgeons were queried which factors were considered for using or not using the robotic platform, the main facilitators of use were perceived usefulness and facilitating conditions (having organizational or technical infrastructure to support use).[32] These concepts tie into the primary idea we posit here: that rather than something more specific to surgeons or patients, it is actually adoption of robotic surgery by the hospital that drives use. This possibility is important because hospital and surgical administrators often make decisions regarding purchase of robotic systems and resource utilization that can have a long-term impact on the services offered to patients and the populations served.

Limitations of this study include its basis on an administrative inpatient database populated by ICD-9 codes. The methodologic changes that occurred in 2012 to the NIS were known to change the number of discharges in the dataset universe by 4%. Hospital identifiers used for the 2010 to 2011 datasets also potentially miscategorized bed size in 10% of hospitals. These factors should be considered when making comparisons from the years 2010 to 2011 to the years 2012 to 2014. We addressed the methodologic changes in the NIS dataset starting in 2012 by using discharge weights for historical NIS files. This minimizes the effects of the redesign on estimated trends that cross the 2012 data year as per HCUP recommendations. The NIS database also only collects information on patients who are admitted to the hospital. As such, elective cholecystectomies and inguinal hernias performed as an outpatient or in a nonhospital surgery center that are often included in a general surgeon's robotic practice are not captured in this data set. Thus, our conclusions regarding factors motivating robotic use are specific to more complex general surgical procedures. It is our opinion that the motivations for incorporating robotics into a general surgeon's practice are different for outpatient operations compared to greater duration, more complex, inpatient operations. The potential benefits regarding visualization and ergonomics are less for short and more straightforward operations, and docking time accounts for a greater percentage of the total operative time. Several authors have noted that among general surgery procedures overall, laparoscopic use is decreasing, whereas robotic use is increasing, but these analyses have also included outpatient procedures.[33,34] The reasons for this increase in robotic use also likely relate robotic teams to institutional factors, but with our methodology we cannot address these issues. Information that may also contribute to robotic use, such as the number of robotic consoles and the vendor policies at individual hospitals, is not available in the NIS database. Starting in 2012, hospital identifiers were replaced with pseudo-identifiers, so that individual hospitals cannot be identified, so it is not possible to collect this information.

It should be noted that other procedures that could be performed robotically were excluded intentionally from this study. Adrenalectomies were not included because they are performed by both general surgeons and urologists. Esophageal surgery was excluded because thoracic surgeons typically perform those operations, and cystectomies were excluded because many institutions perform a hybrid, robotic-open approach for neobladder reconstruction, thereby making it difficult to ascertain which cases are truly minimally invasive.

Robotic utilization in elective general surgery has increased substantially over a short period of time. Beyond the known patient-specific drivers for use, we found a strong association for robotic use in general surgery at hospitals where high proportions of GYN and GU operations were also being performed robotically. This trend persisted when comparing the choice of laparoscopic versus robotic surgery and was independent of patient-specific and other hospital-specific factors. The trends observed in this study confirm that robotic surgery is likely to endure the test of time and will continue to be a part of the general surgical armamentarium despite the paucity of data supporting robotic over laparoscopic surgery and the increased costs of using a robotic platform. Additional study of utilization patterns to better inform quality initiatives in general surgery should be a focus of future research.

Conflict of interest

Dr Yuman Fong has the following disclosures: Scientific consultant Medtronics, Johnson & Johnson, Olympus, Avra Robotics, Perfint Robotics. Drs Dumitra, Nota, Ituarte, Melstrom, Singh, Nathan, and Warner report no biomedical financial interests or potential conflicts of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.1016/j.surg.2019.05.008.

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