Ann Surg Oncol (2019) 26:3216–3223
https://doi.org/10.1245/s10434-019-07550-1

Annals of SURGICAL ONCOLOGY
OFFICIAL JOURNAL OF THE SOCIETY OF SURGICAL ONCOLOGY

ORIGINAL ARTICLE – BREAST ONCOLOGY

The "Nipple Whipple"?! A Pilot Study to Assess the Ergonomic Effects of Nipple-Sparing Mastectomy

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ABSTRACT

Background. Nipple-sparing mastectomies (NSMs) with reconstruction are believed to be more difficult to perform than skin-sparing mastectomies (SSMs), but there is little quantitative data to support this claim.

Methods. This prospective study analyzed four surgeons performing mastectomies. Electromyography (EMG) electrodes placed on selected muscle groups on each surgeon were used to capture muscle exertion intraoperatively and a percentage of maximum voluntary exertion was calculated (%MVE). Data regarding surgeon demographics, exercise habits, musculoskeletal problems, and surgery-specific workload was collected using a questionnaire.

Results. A total of 61 mastectomies were analyzed; 40 were NSM and 21 were SSM/total mastectomies. NSM were considered to be more mentally demanding and physically demanding than SSM ($p < 0.001$). When the surgeons' EMG data was analyzed as a group, there was a statistically significant difference in %MVE for NSM versus SSM at high muscle activity in bilateral anterior deltoid muscle groups and at average muscle activity for the left anterior deltoid muscle only. At low muscle activity, there was a statistically significant increase in activation for SSM versus NSM in bilateral cervical erector spinae. Repeated measures ANOVA was performed, which showed statistically significant differences at high muscle activity between NSM and SSM in the left cervical erector spinae and bilateral anterior deltoid muscles.

Conclusions. Our pilot study shows that intraoperative EMGs can assess muscle activity for mastectomy operations and show a difference between NSM and SSM. This is the first study to provide quantitative data on muscle strain with NSM.

Work-related musculoskeletal disorders (WMSDs) are common among surgeons and may result in everything from shortened operating room days to shortened careers.[1] A recently published literature review found that WMSDs are prevalent with rates ranging from 66 to 94% for open surgery and 23–80% for robotic-assisted surgery. These types of disorders often are underreported to their physicians but can have career-altering effects. Mastectomies in particular are physically taxing on the surgeon due to the complex nature of the procedure and longer operative time, especially as the procedure has changed and become more complex over time.

Nipple-sparing mastectomies (NSMs) with reconstruction are being performed at an increasing rate throughout the world for both breast cancer patients and individuals at high risk for breast cancer, such as gene mutation carriers.[2] There has been an evolution of surgical technique, starting with the Halsted mastectomy and progressing to the modified radical mastectomy, the skin-sparing mastectomy (SSM), and ultimately the nipple-sparing approach, with each procedure removing the breast tissue but leaving more

This work was presented as an oral presentation at the 20th annual meeting of the American Society of Breast Surgeons, Dallas, TX, May 4, 2019.

First Received: 19 April 2019;
Published Online: 24 July 2019

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of the skin envelope and eventually the nipple as the procedure evolved. These modifications of the procedure were primarily implemented to improve the cosmetic and quality of life outcomes for patients, because multiple studies have shown that these newer surgical approaches do not affect the patients' cancer prognosis.[3–5] A systematic analysis of 20 studies of NSM found no significant difference in overall or disease free survival or local recurrence between NSM and SSM or modified radical mastectomy.[5] NSMs are usually performed through an incision on the breast or in the fold under the breast, with the incision ranging significantly in size based on the patient's body habitus, the surgeon, and the reconstructive plan. However, the rise in popularity of the NSM has come at a cost; a recent survey study showed that surgeons reported more physical pain, mental strain, and fatigue for NSM compared with the skin-sparing approach.[6]

While numerous studies have investigated the ergonomic aspects of different surgical procedures, such as gynecologic oncology operations and minimally invasive surgery, there is a paucity of literature for breast surgery.[7] No studies have examined objective data on ergonomic aspects of breast surgery, such as maximum muscle activation. Electromyography (EMG) is a validated tool that has been used in other areas of surgery for ergonomic research and provides objective data to reduce reporting bias. EMG can provide data on the degree of muscle activation for specific muscle groups. We hypothesized that muscle group activation would be higher with a nipple sparing approach to mastectomy compared to a skin sparing approach. Using EMG on four surgeons performing NSM and SSM, we measured muscle group activation in a prospective fashion. Understanding how NSM impacts muscle strain can lead to further investigation in improving techniques for physician discomfort in performing this procedure. If we can develop techniques or interventions to decrease physician discomfort with NSM, then presumably adoption of NSM will increase.

METHODS

Study Design

This institutional review board-approved prospective study analyzed four surgeons performing mastectomies in a single university-affiliated health system. All surgeons are fellowship trained and have been in practice for at least 5 years. Sixty-one consecutive mastectomies were analyzed, and patient consent was not required, because the surgeons, not the patients, were the test subjects. Age, height, weight, and exercise habit information was obtained from the four surgeons before their first case. Immediately following each mastectomy, data regarding musculoskeletal problems and surgery-specific workload were collected using a questionnaire comprised of pertinent questions from the Nordic MusculoSkeletal Questionnaire, the Surgery Task Load Index, and questions specific to mastectomies (Fig. 1).[6,8,9]

Electromyography Analysis

EMG electrodes placed on bilateral cervical erector spinae, upper trapezii, anterior deltoid, and lumbar erector spinae muscle groups on each surgeon were used to capture muscle exertion intraoperatively. EMG analysis started at incision for the mastectomy and ended when the breast specimen was removed from the body. After removal of artifacts from EMG, root-mean-square amplitude was taken every 100 ms, and a histogram was created to find the 10th percentile, 50th percentile (median), and 90th percentile of root mean square (RMS) amplitude during the procedure. These three amplitudes are measures of low, average, and high muscle activity throughout the procedure. The amplitudes were normalized by maximum exertion during isometric contraction, which was performed by the surgeon prior to each procedure. EMG amplitudes are expressed as the percentage of maximum voluntary exertion (%MVE) used by the surgeon. Essentially, this demonstrates what percentage of maximum muscle exertion is used by a surgeon in the tested muscle groups in times of low, average, and high muscle activity.

Statistical Analysis

Analysis of the surgeons' survey data was performed using the Wilcoxon rank-sum and Fisher's exact tests. Univariable comparisons of EMG data were made using the Wilcoxon rank-sum test. EMG data also was analyzed using repeated-measures analysis of variance (ANOVA), which included covariates for surgeon, duration of procedure, left or right side, first or second breast of the procedure, and procedure type (NSM or SSM). All statistical analysis was performed using SAS 9.3 (SAS Institute, Cary, NC), with two-tailed tests and a significance level of $p < 0.05$. No adjustments for multiple comparisons were made.

RESULTS

A total of 61 mastectomies were analyzed; 40 were NSM (36 NSM as part of a bilateral operation, 4 NSM were unilateral), and 21 were SSM or total mastectomies (14 SSM/total mastectomies as part of a bilateral operation, 7 SSM/total were unilateral). Table 1 lists demographic

Name: 1-KK 2-CP 3-KY 4-DW

Date surgey completed: ____________________

Surgery Start Time:________ / Surgery End Time:________

EHS-18-243: Tell Me Where it Hurts- The Ergonomic Effects of Mastectomies on the Operating Surgeon

Ergonomoics Questionnaire

(Complete after Each surgery and one for each side surgery is completed)

Please complete the below questions immediately following the procedure:

1. Nipple-Sparing skin incision location: Inframammary Fold Lateral Radial Inferior Vertical Wise
Other:____________________ N/A

2. Skin-Sparing skin incision location: Elliptical Wise
Other:____________________ N/A

3. Total Mastectomy skin incision location: Elliptical Wise
Other:____________________ N/A

4. Weight of breast specimen: __________

5. Patient's BMI: (please obtain from anesthesiologist)

6. Has the patient had a prior breast reduction? Yes_______ No_______

7. Was a headlight worn during the procedure? Yes_______ No_______

8. Was a lighted retractor used during the procedure? Yes_______ No _______

9. Who was your first assist? Resident ________ PA__________ Attending surgeon ________

10. What was the reason for surgery? Cancer _______ Prophylactic _________

11. If this is a bilateral procedure, was this your first or second side? First Right/Left Second Right/Left N/A

Using a 0-10 scale answer the questions below:

1. How mentally demanding was the procedure? ______
(0=not demanding at all; 10=extremely demanding)

2. How mentally demanding was the procedure? ______
(0=not demanding at all; 10=extremely demanding)

3. Compared to other mastectomies this type, how difficult was this operation? _____
(0=not difficult at all; 10=extremely difficult)

4. How difficult was visualization during the operation? ______
(0=not difficult at all; 10=extremely difficult)

5. What is your degree of satisfaction with the equipment availabe to complete the surgery? ______
Please note this scale is different than those above (0=not satisfied at all; 10= extremely satisfied)

NECK

How to answer the questionnaire: By neck trouble is meant ache, pain or discomfort in the shaded area. Please concentrate on this area, ignoring any trouble you may have in adjacent parts of the body. There is a seperate questionnaire for shoulder trouble.

Please answer by putting a cross in the appropriate box – one cross for each question. You may be in doubt as to how to answer, but please do your best anyway.

1. Have you ever had neck trouble (ache, pain or discomfort)?
1 ☐ No 2 ☐ Yes ☐

If you answered No to Question 1, do not answer the questions 2–8.

2. Have you ever hurt your neck in an accident?
1 ☐ No 2 ☐ Yes ☐

3. Have you ever had to change jobs or duties because of neck trouble?
1 ☐ No 2 ☐ Yes ☐

4. What is the total length of time that you have had neck trouble during the last 12 months?
1 ☐ 0 days
2 ☐ 1–7 days
3 ☐ 8–30 days
4 ☐ More than 30 days, but not every day
5 ☐ Every day ☐

If you answered 0 days to Question 4, do not answer the Questions 5–8.

5. Has neck trouble caused you to reduce your activity during the last 12 months?
a. Work activity (at home or away from home)?
1 ☐ No 2 ☐ Yes ☐
b. Leisure activity?
1 ☐ No 2 ☐ Yes ☐

6. What is the total length of time that neck trouble has prevented you from doing your normal work (at home or away from home) during the last 12 months?
1 ☐ 0 days
2 ☐ 1–7 days
3 ☐ 8–30 days
4 ☐ More than 30 days
5 ☐ Every day ☐

7. Have you been seen by a doctor, physiotherapist, chiopractor or other such person because of neck trouble during the last 12 months?
1 ☐ No 2 ☐ Yes ☐

8. Have you had neck trouble at any time during the last 7 days?
1 ☐ No 2 ☐ Yes ☐

FIG. 1 Surgeon questionnaire post-surgery

characteristics of the surgeons, patients, and procedure. NSM took more time than SSM (49.2 ± 11.3 min vs. 36.3 ± 11.7 min, $p < 0.001$). In regards to patient selection, SSM was performed more often on larger patients compared with NSM (BMI 26.6 ± 4.8 vs. BMI 23.8 ± 5.1, $p = 0.013$), and breast specimens also were larger (553 ± 292 g vs. 345 ± 191 g, $p = 0.006$). A lighted retractor was used in 90% of NSM compared with 14% of SSM ($p < 0.001$).

NSM were considered to be more mentally demanding ($p < 0.001$) and physically demanding ($p < 0.001$) than SSM. Visualization was deemed more difficult in NSM compared with SSM ($p < 0.001$). Surgeons were more satisfied with the available equipment when performing SSM compared with NSM ($p < 0.001$) (Table 1).

When the surgeons' EMG data were analyzed as a group, there was a statistically significant difference of %MVE at high muscle activity (90th percentile muscle activation) for NSM compared with SSM for the left (58 ± 8 vs. 52 ± 12, $p = 0.038$) and right (59 ± 10 vs. 52 ± 8, $p = 0.005$) anterior deltoid muscle groups (Table 2; Fig. 2). In other words, NSM procedures require 58% of the surgeon's maximum exertion during the time of highest muscle activity compared to 52% of their maximum exertion for SSM in the left anterior deltoid. NSM procedures require 59% of the surgeon's maximum exertion during the time of highest muscle activity compared with 52% of their maximum exertion for SSM in the right anterior deltoid. When analyzing the average muscle activity (50th percentile muscle activation) of the anterior deltoid muscle for NSM versus SSM, there was a statistically significant increase in activation for the left (18 ± 7 vs. 14 ± 4, $p = 0.045$) but not for the right, even though the mean exertion was higher on the right as well (19 ± 10 vs. 14 ± 7, $p = 0.125$). Therefore, NSM procedures require 18% of the surgeon's maximum exertion during the time of average muscle activity compared with 14% of their maximum exertion for SSM for the left anterior deltoid. During the period of low muscle activity (10th percentile muscle activation), there was a significant increase in activation for SSM versus NSM in both the left and right cervical erector spinae ($p = 0.023$ and $p = 0.019$, respectively).

The surgeons' EMG data also were analyzed individually and the results varied by surgeon. There were no tested muscle groups that showed statistically significant differences in activation at either the 10th, 50th, or 90th percentiles in all four surgeons for NSM versus SSM, when analyzed individually.

TABLE 1 Demographic characteristics of the surgeon, patient, and operation stratified by procedure type

	Nipple-sparing (N = 40)	Skin-sparing/total (N = 21)	p value
Surgeon characteristics			
Age (yr) [Mean ± SD]	45.5 ± 8.3	47.8 ± 8.7	0.177
Height (in) [Mean ± SD]	59.6 ± 3.6	70.4 ± 4.2	0.683
Weight (lb) [Mean ± SD]	157.2 ± 21.7	162.1 ± 25.1	0.683
BMI (kg/m^2) [Mean ± SD]	22.7 ± 0.8	22.8 ± 0.8	0.683
Routinely exercises [N (%)]	32 (80.0)	14 (66.7)	0.251
Surgeon			0.196
1	12 (30.0)	2 (9.5)	
2	8 (20.0)	7 (33.3)	
3	12 (30.0)	5 (23.8)	
4	8 (30.0)	7 (33.3)	
Patient characteristics			
Weight of breast specimen (g) [Mean ± SD]	345 ± 191	553 ± 292	**0.006**
Patient's BMI (kg/m^2) [Mean ± SD]	23.8 ± 5.1	26.6 ± 4.8	**0.013**
Prior breast reduction [N (%)]	3 (7.5)	0 (0.0)	0.545
Procedure characteristics			
Skin incision location [N (%)]			< **0.001**
Inframammary fold	36 (90.0)	–	
Lateral Radial	2 (5.0)	–	
Inferior Vertical	2 (5.0)	–	
Elliptical	–	15 (71.4)	
Other: tear drop vertical/vertical/double circle	–	6 (28.6)	
Headlight worn [N (%)]	16 (40.0)	9 (42.9)	0.829
Lighted retractor [N (%)]	36 (90.0)	3 (14.3)	< **0.001**
First assist [N (%)]			0.486
Resident	25 (62.5)	15 (71.4)	
PA	15 (37.5)	6 (28.6)	
Reason for surgery [N (%)]			0.142
Cancer	15 (37.5)	12 (57.1)	
Prophylactic	25 (62.5)	9 (42.9)	
Side, first or second [N (%)]			0.079
First	18 (45.0)	7 (33.3)	
Second	18 (45.0)	7 (33.3)	
Unilateral procedure	4 (10.0)	7 (33.3)	
Side, left or right [N (%)]			0.596
Left	20 (50.0)	9 (42.9)	
Right	20 (50.0)	12 (57.1)	
Duration of surgery (min) [Mean ± SD]	49.2 ± 11.3	36.3 ± 11.7	< **0.001**
Surgeon questionnaire post-surgery			
Using a 0–10 scale and the questions below: [Mean ± SD]			
How mentally demanding was the procedure?	5.4 ± 2.5	2.5 ± 2.0	< **0.001**
How physically demanding was the procedure?	5.9 ± 2.5	2.1 ± 1.7	< **0.001**
Compared to other mastectomies this type, how difficult was this operation?	5.5 ± 2.7	2.5 ± 1.9	< **0.001**
How difficult was visualization during the operation?	5.7 ± 2.8	2.7 ± 2.2	< **0.001**
What is your degree of satisfaction with the equipment available to complete the surgery?	6.8 ± 2.1	8.3 ± 1.6	< **0.001**

Bold values are statistically significant (p < 0.05)

TABLE 2 Electromyography data for muscle groups from all surgeons at selected muscle activity levels, stratified by procedure

	Nipple-sparing (N = 40)	Skin-sparing (N = 21)	P value	Nipple-sparing (N = 40)	Skin-sparing (N = 21)	P value
	Left			Right		
	Mean %MVE ± SD	Mean %MVE ± SD		Mean %MVE ± SD	Mean %MVE ± SD	
Cervical erector spinae						
10th percentile	14.9 ± 3.9	17.3 ± 4.7	**0.023**	14.0 ± 3.7	16.9 ± 4.9	**0.019**
50th percentile	34.3 ± 6.5	36.8 ± 7.8	0.187	33.0 ± 5.5	35.2 ± 5.5	0.129
90th percentile	69.1 ± 5.4	67.8 ± 9.3	0.773	66.5 ± 6.8	66.1 ± 6.4	0.457
Upper trapezius						
10th percentile	6.8 ± 4.9	7.8 ± 5.5	0.574	7.4 ± 5.2	7.1 ± 5.3	0.786
50th percentile	32.9 ± 12.1	34.5 ± 8.7	0.627	31.2 ± 8.4	29.9 ± 10.5	0.716
90th percentile	72 ± 9.1	70.2 ± 8	0.362	69.7 ± 8.9	68.1 ± 7.4	0.325
Anterior deltoid						
10th percentile	6.6 ± 3.8	5.6 ± 2.3	0.574	6.5 ± 5.4	6.1 ± 4.1	0.915
50th percentile	17.8 ± 7.1	14.0 ± 4.3	**0.045**	18.5 ± 10	14.4 ± 6.5	0.125
90th percentile	57.9 ± 7.5	51.7 ± 11.8	**0.038**	58.7 ± 10.2	51.9 ± 7.6	**0.005**
Lumbar erector spinae						
10th percentile	7.6 ± 5.1	7.6 ± 4.3	0.781	10.2 ± 4.9	9.6 ± 3.3	0.871
50th percentile	21.8 ± 10.2	24.4 ± 9.8	0.326	25.4 ± 8.6	24.8 ± 8.2	0.648
90th percentile	61.8 ± 12.8	65.7 ± 7.8	0.182	60.7 ± 14.1	63.6 ± 9.8	0.593

Bold values are statistically significant ($p < 0.05$)

%MVE = Percentage of maximum voluntary exertion of a tested muscle group

Repeated measures ANOVA was performed, which included duration of surgery, left versus right breast, first versus second side in bilateral procedures, surgeon, and procedure type (NSM or SSM). This analysis showed significant differences at the 90th percentile muscle activation between NSM and SSM in the left cervical erector spinae, left anterior deltoid muscle, and right anterior deltoid muscle ($p = 0.021$, $p = 0.012$, and $p = 0.012$ respectively; Table 3). No other muscle group showed significant differences between NSM and SSM at the 10th, 50th, or 90th percentiles.

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DISCUSSION

The current study is the first to our knowledge to quantitatively analyze muscle exertion and surgeon workload of nipple-sparing mastectomies. Similar to other qualitative studies, our surgeons reported that NSM was more mentally and physically demanding than SSM.[6] However, we now have quantitative data that shows that surgeons performing NSM exert their cervical spinae and anterior deltoid muscles more than with SSM. This finding persisted despite the duration of surgery, whether it was a bilateral procedure or not or whether the mastectomy was left sided or right sided. These findings are significant for many reasons. The same CPT code is used for NSM and SSM, and based on our findings, it is clear that NSM are more difficult operations.[10] Nipple-sparing mastectomies are still only performed in a minority of breast centers.[11] The reasons for that are not well understood but may be related to the perceived difficulty of the procedure and the lack of reimbursement for this increased surgical difficulty and operative time. Concern about equivalent efficacy of NSM compared with non-NSM mastectomy may play a role as well. Lighted retractors were used during the majority of cases, in hopes of improving illumination of the surgical field.[12] However, visualization was still considered to be more difficult in NSM.

A significant difference was noted in muscle exertion at times of high muscle activity (90th percentile) for the bilateral anterior deltoid muscles in NSM compared with SSM. The deltoid muscle plays a significant role in the function of the shoulder and is composed of three distinct portions; anterior, middle, and posterior. It acts mainly as an abductor of the shoulder and stabilizer of the humeral head.[13] Ninety percent of NSMs in this study were performed through an inframammary fold incision, and all of our surgeons were right-handed. This incision placement means that the surgeon's line of sight is parallel to the operating field as opposed to vertical (in SSM) and requires either the table to be raised or the surgeon to sit on a stool

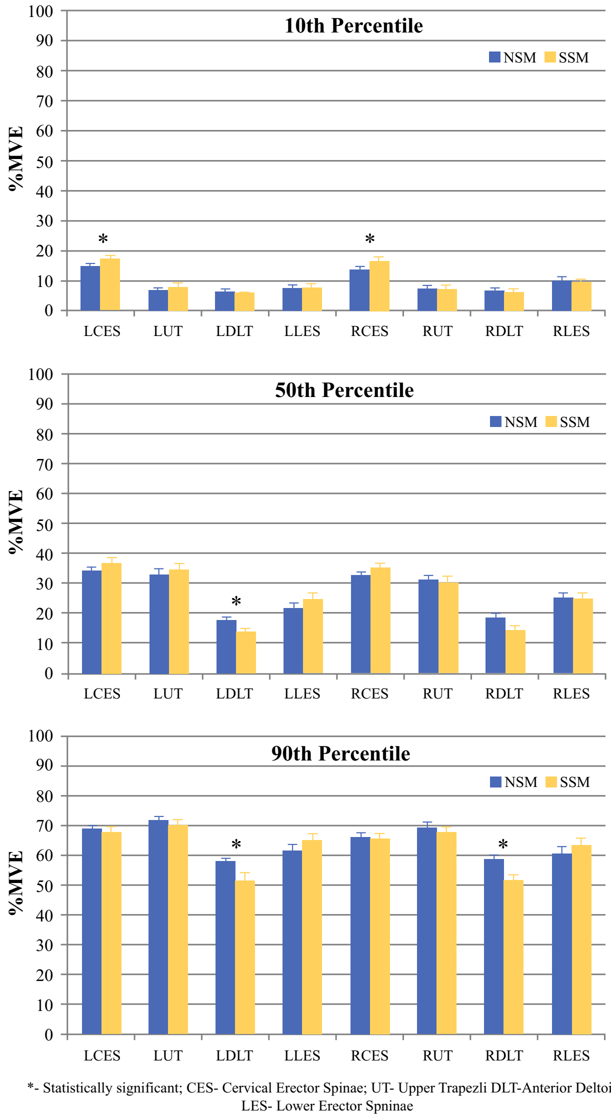

FIG. 2 Graphs of electromyography data for muscle groups from all surgeons at selected muscle activity levels, stratified by procedure at **a** low activity (10th percentile), **b** average activity (50th percentile), and **c** high activity (90th percentile)

TABLE 3 ANOVA analysis of maximum voluntary muscle exertion (%MVE) for NSM versus SSM by muscle group at low, average, and high activity levels

	Left *p value*	Right *p value*
Cervical erector spinae		
10th percentile	0.240	0.175
50th percentile	0.755	0.781
90th percentile	**0.021**	0.207
Upper trapezius		
10th percentile	0.861	0.612
50th percentile	0.207	0.995
90th percentile	0.888	0.821
Anterior deltoid		
10th percentile	0.285	0.886
50th percentile	0.060	0.134
90th percentile	**0.012**	**0.012**
Lumbar erector spinae		
10th percentile	0.941	0.620
50th percentile	0.713	0.539
90th percentile	0.675	0.723

All analyses are controlled for duration of surgery, left versus right breast, first versus second side in bilateral procedures, and surgeon

Bold values are statistically significant ($p < 0.05$)

for the procedure.[14] The shoulders are maximally activated during this procedure, either holding the retractor or retracting the gland with the nondominant hand and performing the dissection with the dominant hand. In contrast, with a skin-sparing mastectomy, the surgeon's line of sight is vertical and therefore less shoulder activation is required for visualization, retraction, and dissection. As the surgeons who perform this procedure, this finding was not surprising as we have all suffered from sore shoulders after an operating room day of NSMs. Further analysis on the amount of time the surgeon spends retracting the skin flap as opposed to the assistant may help to decrease this shoulder strain in the future.

When the average muscle activity exertion was analyzed (50th percentile), the left deltoid showed a statistically significant increase in NSM however the right deltoid did not reach statistical significance. This may be due to continued retraction during NSM of the nondominant hand (left in this study) to maintain visualization while the dominant hand (right in this study) relaxes in general when not dissecting.

The only statistically significant finding of increased %MVE value in SSM compared with NSM was at low muscle activity (10th percentile), and this was noted in the bilateral cervical erector spinae muscles. The bilateral cervical erector spinae (CES) muscles, in conjunction with other muscles, provide extension of the spine and head. Higher CES activity could presumably be due to more anterior translation of the head (increased neck flexion angle) during SSM due to the vertical line of site, with the cervical erector muscles needing to support the weight of the head and neck.[14,15]

When the surgeon's EMG results were analyzed and compared, there was considerable variability. A nipple-sparing mastectomy, even when performed through the same type of incision, can vary widely in technical aspects, and these changes could lead to changes in muscle activation.[16] Stucky and colleagues published that EMG muscle activation/strain does not always correlate with the areas of reported muscle pain.[17] Posture during surgery and exercise habits of the surgeon have been reported in plastic surgery as important determinants of musculoskeletal pain.[18] The variability seen between surgeons in terms of ergonomic workload also could be due to patient characteristics, such as patient stature, ptosis of the breast, pathology, and location in the breast of the pathology.[19] Our study looked at patient BMI and breast specimen weight; however, there are multiple other factors that we may not have captured.

This study is not without limitations. This was a small pilot study and included only 4 surgeons and 61 cases. No statistical adjustments for multiple comparisons were made, which may have led to an inflated family-wise error rate and possible false-positive *p*-values. EMG analysis can be compromised during the usage of electrocautery, and all of our surgeons use electrocautery at some point during these surgeries. The muscles chosen for EMG analysis were based on previously reported surgical ergonomics studies, which indicate neck and back issues in surgeons but not breast surgeries specifically.[20] It is possible we may be missing certain pertinent muscle groups. Forearm and hand muscles are used extensively during mastectomies; however, we were unable to analyze these due to concerns with sterility or interfering with surgical technique.

CONCLUSIONS

Our pilot study shows that intraoperative EMGs can assess muscle activity for mastectomy operations and show a difference between NSM and SSM. This is the first study to provide quantitative data on muscle strain with NSM. Better retractors, which allow for gentle retraction with minimal need for repositioning, may be able to improve shoulder strain in the operating surgeon. A standardized protocol for optimal surgeon positioning at different points of the procedure may improve the ergonomic workload. Improved light sources and instrumentation could improve the mental difficulties. Future studies could lead to the development of protocols or devices that lessen muscle strain as well as physician reported workload and musculoskeletal problems associated with NSM.

ACKNOWLEDGMENT The authors thank Jennifer Jaffe for her help with preparing the manuscript and figures for publication.

DISCLOSURE The authors do not have anything to disclose.

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