The endotracheal (ET) tube and laryngeal mask airway (LMA) are widely used airway devices in the practice of anesthesia. The most common adverse event reported by patients postoperatively after use of an ET tube or LMA is a sore throat and hoarseness.1,2 Other adverse pharyngolaryngeal complications that have been reported with ET tube use include lingual nerve damage, ulceration, bleeding, and tracheal stenosis, necrosis, or rupture.3-7 For the LMA, these complications include sore neck, dysphagia, venous neck congestion, arytenoid cartilage dislocation, lingual nerve damage, and jaw tenderness.2,8-17 These complications have been reported to be associated with higher cuff pressures, especially when they exceed recommended pressures.1,2 For example, Liu et al1 found a sore throat incidence of 44% in patients whose mean ET tube cuff pressure exceeded 43 ± 23.3 mm Hg. Wong et al8 reported an incidence of sore throat in 56.5% of pediatric patients whose LMA cuff pressures exceeded 100 cm H2O. Pressures of ET tubes should be maintained between 20 and 30 cm H2O (27-40 mm Hg),4,18 and LMA devices below 60 cm H2O (44 mm Hg).2 Several investigations have demonstrated that use of a manometer to maintain ET tube1 and LMA2 cuff pressures at the recommended ranges reduces the incidence of pharyngolaryngeal complications.

Liu et al1 conducted a multicenter randomized controlled trial in 509 adult patients undergoing general anesthesia (no nitrous oxide [N2O] administered) who were randomly assigned to either a manometer group or control group. Anesthesia providers inflated the ET tube cuffs of all patients using the palpation method, after which patients in the manometer group had their cuff pressures adjusted between 15 and 25 mm Hg, whereas the control group did not. Mean ET tube cuff pressures in the manometer group was 43 ± 23.3 mm Hg before adjustment (the highest was 210 mm Hg) and 20 ± 3.1 mm Hg after adjustment. Investigators found that using a manometer to adjust ET tube cuff pressures reduced the incidence of sore throat (34% vs 44%, P = .033), hoarseness (3% vs 11%, P = .001), and blood-streaked expectoration (4% vs 11%, P = .002) compared with the control group, in which ET tube cuff pressures were not adjusted or measured. Similar findings have been reported when a manometer was used to reduce LMA cuff pressures. Seeet et al9 randomly assigned 203 adult patients undergoing surgery with general anesthesia via an LMA (no N2O administered) to a manometer group with cuff pressures adjusted between 40 and 44 mm Hg (< 60 cm H2O) or a routine care group. Their primary outcome was the difference in “composite pharyngolaryngeal adverse events” (sore throat, dysphagia, and dysphonia) that occurred at 1, 2, or 24 hours postoperatively. After placement of the...
LMA, the mean initial cuff pressure in the manometer group was 112 ± 59 mm Hg compared with 114 ± 57 mm Hg in the routine care group. The use of a manometer significantly decreased the incidence of pharyngolaryngeal complications (13.4% vs 45.6%, P < .001). At 2 and 24 hours the incidence of sore throat was significantly lower in the manometer group vs routine care (2.1% vs 8.7%, P = .038, and 3.1% vs 13.6%, P = .008, respectively). Similar findings were found for dysphagia, with lower rates in the manometer group overall, although the difference did not reach statistical significance (P = .05). Hoffman et al,20 studying 200 patients, found that limiting the LMA cuff pressure to a “minimal airtightness pressure” (< 60 cm H2O) reduced the incidence of sore throat from 8% to 0% (P < .001) compared with a non-adjusted group whose cuffs were inflated with standard volumes. Bureg et al,19 studying 200 patients, found that limiting the LMA cuff pressure to “minimal airtightness pressure” (< 60 cm H2O) reduced the incidence of sore throat from 8% to 0% compared with a non-adjusted group for which the mean LMA cuff pressure was 192 ± 32 cm H2O.

Despite evidence supporting the adjustment of ET tube and LMA cuff pressures to recommended ranges, the monitoring of intracuff pressures in ET tubes and LMAs with manometers is not widely practiced by anesthesia providers. Even at our hospital, which has manometers in every operating room for easy access by anesthesia providers, there is varied use of the instrument. Many providers will palpate pilot balloon pressure and use their finger’s tactile sense as a subjective measure of intracuff pressure. Other methods include “minimal leak” or injecting a predetermined volume of air. Many studies have shown these methods to be inaccurate. In a study of 40 anesthesia providers, Stewart et al found that providers obtained an initial ET tube cuff pressure above 40 cm H2O in 65% of patients using their preferred method of estimation (palpation: 88%, minimal leak: 10%, or predetermined volume: 2%). Sengupta et al,18 studying 93 patients, found an initial ET tube cuff pressure greater than 30 cm H2O in 50.5% of cases. Hoffman et al,21 in a study of 41 emergency medicine attending physicians, found that providers obtained an initial ET tube cuff pressure above 120 cm H2O in 90% of cases using the palpation method. Trivedi et al,4 studying 75 patients, found that providers obtained an initial ET tube cuff pressure above 30 cm H2O in 26.2% of cases.

Despite the evidence, these methods continue to be used clinically to estimate the cuff pressures in ET tubes and LMAs. At our institution, we did not have any evidence-based practice (EBP) guidelines to aid the anesthesia provider in setting, monitoring, or documenting intracuff pressures. We also did not have a standardized way to consistently document intracuff pressures in the anesthesia record, nor did we have a method for providing quality assurance data on what pressures were maintained throughout the intraoperative period. An EBP quality improvement project was undertaken to align clinical practice with current evidence that suggests that regularly checking and adjusting ET tube and LMA cuff pressures to within normal ranges decreases the incidence of pharyngolaryngeal complications.1,2 Evidence also suggests that simple reminders (automated via the electronic medical record or posted) improve compliance with guidelines. Therefore, the purpose of this EBP quality improvement project was to explore whether an educational intervention, physical reference cards, and a prominent cuff pressure documentation variable in the electronic anesthesia record would increase the frequency of provider monitoring of intracuff pressures and thereby decrease the occurrence of high intraoperative ET tube and LMA cuff pressures.

Methods

The institutional review board (IRB) at Naval Medical Center San Diego in San Diego, California, determined this project was quality improvement and did not require IRB review. The IRB at The University of Alabama, Tuscaloosa, Alabama, approved this study after expedited review (IRB #15-OR-117-ME). Patient consents were not required because monitoring intracuff pressures is accepted practice, within the purview of anesthesia providers, and the pressure manometers used were not experimental. No personal identifying information about the patients or providers was obtained. This EBP quality improvement project used the Iowa Model of Evidence-Based Practice Theory and involved 3 phases.

The first phase was a baseline evaluation of the intracuff pressures of 51 ET tubes and 51 LMAs in surgical patients undergoing general anesthesia obtained as a convenience sample over a 10-day period. After verifying that the patient was 18 years or older, the investigator asked anesthesia providers whether they had checked the intracuff pressure of the ET tube or LMA after placement and whether the pressure needed adjustment. Providers were also asked about the use of N2O before the point of data collection. The investigator then checked and recorded the intracuff pressure of the ET tube or LMA. This pressure was shared with the anesthesia provider and adjusted as requested. Data on demographic and clinical characteristics collected included N2O use, cuff type (ET tube or LMA), cuff size, patient’s height and weight, and provider type. Provider type included anesthesiologists and Certified Registered Nurse Anesthetists.
(CRNAs) working alone or with student nurse anesthetists (SRNAs) and anesthesiologists working with anesthesia residents. Each patient’s BMI was calculated using the standard formula of weight in kilograms divided by the height in meters squared.

In phase 2, the investigator presented to the anesthesia department a summary of 4 studies showing reduced postoperative pharyngeal complications when ET tube and LMA cuff pressures were controlled and 3 studies showing the inaccuracy of pilot balloon palpation. The investigator also shared the results of the phase 1 survey, including the mean, minimum, and maximum pressures recorded for ET tubes and LMAs, and the frequency of self-reported monitoring by providers. Recommended cuff pressures for ET tubes and LMAs were also discussed. The investigator created a prominent cuff pressure documentation variable in the electronic anesthesia record (Figure 1) and placed a physical reference card of recommended cuff pressures in all operating rooms (Figure 2). All departmental staff were emailed the educational presentation, and those who missed the live presentation were given a summary of the information in person by the investigator. This included a couple of reservists who initially came to training during phase 3 of the study.

After a 2-day period, the investigator conducted phase 3, evaluating the intracuff pressures of another 51 ET tubes and 51 LMAs in surgical patients undergoing general anesthesia, in the same manner as that for phase 1, over an 11-day period. The investigator then compared the postintervention results with the initial baseline survey. Outcomes of interest were the percentage of providers monitoring ET tube or LMA intracuff pressures and the mean differences in intracuff pressures before and after the interventions. Before this project, a power analysis was performed with an \( \alpha = 0.05 \) and a \( \beta = 0.80 \). We set a conservative goal to both increase provider monitoring of intracuff pressures and reduce the proportion of high intracuff pressures by 25%. We then added 10% to each group as a safety measure against insufficient power and settled on a sample size of 51 for each pre- and postgroup of ET tubes and LMAs, with a final sample size of 204.

Descriptive and inferential statistics were used to analyze the results. Chi-square tests were used to examine the relationship between time period (pre- or postintervention) and frequency of providers monitoring intracuff pressures, whereas independent-samples \( t \) tests were used to examine differences in mean pre- and postintervention intracuff pressures in each cuff type (ET tube
A Pearson correlation showed that there was no relationship between initial ET tube cuff pressure and weight. This also held true for LMA initial cuff pressure and weight or BMI. Our results showed no relationship between initial ET tube cuff pressure and patient weight or BMI. Our results showed no relationship between initial ET tube cuff pressure and patient weight or BMI. This was also held true for LMA initial cuff pressure and weight. Data were analyzed using SPSS version 23 software.

### Results

The intracuff pressures were measured in a total of 102 ET tubes and 102 LMAs (51 in each group before and after the intervention). There were no significant differences in demographic or clinical characteristics, including provider type, between the pre- and postintervention groups except patient weight and BMI in the ET tube group. Mean (± SD) patient weight for the ET tube preintervention group was 84.2 ± 18.9 kg, whereas the postintervention group mean was 76.4 ± 18.2 kg. Because of this difference, a Pearson correlation was conducted to check for a relationship between initial ET tube cuff pressure and patient weight or BMI. Our results showed no relationship between initial ET tube cuff pressure and weight (r = −0.01, P = 0.993), or BMI (r = 0.029, P = 0.771). This also held true for initial LMA cuff pressure and weight (r = 0.010, P = 0.918), or BMI (r = −0.041, P = 0.686).

The interventions significantly increased the frequency at which providers monitored ET tube and LMA intracuff pressures and decreased intracuff pressures in both groups. Providers monitored the pressures of ET tubes in 39 (77%) of the preintervention cases vs 48 (94%) of the postintervention cases (P = 0.025). The pressures of LMAs were monitored by providers in 19 (37%) of the preintervention cases vs 48 (94%) of the postintervention cases (P < 0.001; Figure 3). In the preintervention group, mean ET tube cuff pressure was 34 ± 16 cm H₂O (minimum = 12 cm H₂O; maximum = 85 cm H₂O) compared with 29 ± 12 cm H₂O (minimum = 17 cm H₂O; maximum = 80 cm H₂O) in the postintervention group (P = 0.045; Figure 4). Only 24 (47%) of the ET tubes had pressures of 30 cm H₂O or less in the preintervention group compared with 37 (73%) of the ET tubes in the postintervention group (P = 0.015). The preintervention mean LMA cuff pressure was 73 ± 30 cm H₂O (minimum = 21 cm H₂O; maximum > 120 cm H₂O) compared with 49 ± 15 cm H₂O (minimum = 15 cm H₂O; maximum > 120 cm H₂O) in the postintervention group (P < 0.001; see Figure 4). In the preintervention group only 23 (45%) of the LMAs had pressures of 60 cm H₂O or less compared with 47 (92%) of the LMAs in the postintervention group (P < 0.001).

The use of N₂O increased intracuff pressures in both ET tubes and LMAs. Combining pre- and postintervention groups, the mean ET tube cuff pressure without N₂O use (n = 93) was 30 ± 13 cm H₂O, whereas the mean ET tube cuff pressure with N₂O use (n = 9) was 49 ± 18 cm H₂O (P < 0.001). Combining pre- and postgroups, the mean LMA cuff pressure without N₂O use (n = 91) was 59 ± 25 cm H₂O, and the mean LMA cuff pressure with N₂O use (n = 11) was 81 ± 33 cm H₂O (P = 0.052).

### Discussion

This study showed that an educational intervention, physical reference cards, and a prominent cuff pressure variable in the electronic anesthesia record for documenting cuff pressures were effective at increasing provider monitoring and adjustment of intracuff pressures as well as reducing the mean cuff pressures seen intraoperatively. In the preintervention groups, we found a mean ET tube cuff pressure of 34 ± 16 cm H₂O and a mean LMA cuff pressure of 73 ± 30 cm H₂O. These measures were lower than the pressures found in other studies, a difference most likely due to a higher baseline frequency of providers monitoring intracuff pressures in ET tubes (77%) and LMAs (37%) at our facility. We were surprised that we effected only a small change in the range of intracuff pressures after the intervention. There was a small decrease in the maximum ET tube pressure, but the LMA maximum pressure after the intervention was still greater.

| Characteristic | ET tube | | LMA | |
|---------------|---------|---|---|
| **Pre** | **Post** | P | **Pre** | **Post** | P |
| Height (in), mean ± SD | 67 ± 4.6 | 66.5 ± 4.1 | .556 | 68 ± 4.7 | 66.8 ± 3.9 | .193 |
| Weight (kg), mean ± SD | 84.2 ± 18.9 | 76.4 ± 18.2 | .035 | 77.3 ± 16.3 | 77.3 ± 15 | < .001 |
| BMI (kg/m²), mean ± SD | 29.2 ± 6.5 | 26.7 ± 5.3 | .033 | 26 ± 5.1 | 26 ± 5.1 | .405 |
| N₂O used, No. (%) | 4 (7.8) | 5 (9.8) | .500 | 6 (11.8) | 5 (9.8) | .750 |
| Device size, | | | | | | |
| 5.5 | 0 (0) | 1 (2) | | | | |
| 7.0 or 3 | 26 (51) | 20 (39.2) | | 3 (5.9) | 3 (5.9) | |
| 7.5 or 4 | 18 (35.3) | 24 (47) | | 26 (51) | 29 (56.9) | |
| 8.0 or 5 | 7 (13.7) | 6 (11.8) | | 22 (43.1) | 19 (37.2) | |

Table. Demographic and Clinical Characteristics of Population in Preintervention and Postintervention Groups (N = 204)³

Abbreviations: BMI, body mass index; ET, endotracheal; LMA, laryngeal mask airway; N₂O, nitrous oxide.

³A Pearson correlation showed that there was no relationship between initial ET tube cuff pressure and weight (r = −0.001, P = 0.993) or BMI; r = 0.029, P = 0.771). This also held true for LMA initial cuff pressure and weight (r = 0.010, P = 0.918) or BMI (r = −0.041, P = 0.686).
than 120 cm H2O. These higher pressures were because 3 (6%) of the providers did not check intracuff pressures in ET tubes and LMAs after the intervention. In fact, nearly all postintervention pressures that were above recommended limits were due to either providers not initially checking the intracuff pressure or checking and adjusting the pressure, but then not rechecking it later while using N2O. Providers who use N2O should consider checking and adjusting intracuff pressures more frequently.

Limitations of this project included a small sample size, short timeframe, and observer bias. Baseline frequency of providers monitoring intracuff pressures at our facility was likely higher than at other facilities because of the availability of manometers. Manometers are relatively cheap ($200-$500 each) and last for many years with minimal maintenance. Monitoring intracuff pressures is an easy task for providers to perform, but they must be provided the equipment. Without this equipment, providers are forced to use methods that have been shown to be inaccurate and result in high intracuff pressures (palpation, minimal leak, and predetermined volume).4,18,21,22 Given the increasing evidence that monitoring and reducing intracuff pressures can decrease postoperative pharyngeal complications1,2 the use of manometers combined with provider education could have tangible and intangible benefits to patients, providers, and facilities. For patients, this means decreasing the rates of postoperative sore throat, sore neck, hoarseness, dysphagia, nerve damage, mucosal ulceration, and bleeding, as well as tracheal stenosis, necrosis, or rupture. These complications could lead to longer hospitalizations, the need for additional medications or higher doses to manage symptoms, lost work to care for self or family members, the need for further surgery to repair damage to the trachea and/or pharynx, and long-term sequelae with increased morbidity. These consequences ultimately lead to decreased patient satisfaction. For anesthesia providers and facilities, these complications present an increased cost of care, decreased patient safety, an increased exposure to medical-legal proceedings, a declining patient base as dissatisfied patients seek care elsewhere, and ultimately reduced funding. Viewed in these terms, the advantage of a protocol that includes providing manometers, educating anesthesia providers on the importance of monitoring cuff pressures, providing prominent reference cards of recommended cuff pressures, and including a documentation variable in the electronic anesthesia record becomes clear. Other facilities could observe a significant improvement in cuff pressures by providing manometers and implementing a protocol similar to the one used in this project.

The next steps in this project will be to develop an automated report that can retrieve cuff pressure data from the electronic anesthesia records and provide quarterly reports to providers on their rate of monitoring cuff pressures. Future research could explore sustainment techniques including the optimal frequency of these interventions, the effectiveness of regular feedback to providers on their monitoring performance, and the effect of providing patient satisfaction or other outcomes data on provider behavior and performance related to the monitoring of intracuff pressures.

REFERENCES

AUTHORS
CDR Randy E. Ashman, MSN, DNP, CRNA, NC, USN, is an active-duty CRNA in the United States Navy. He currently serves as a nurse anesthetist at the Naval Medical Center, San Diego, California. Email: randy@ashmans.net.
Susan J. Appel, PhD, APRN-BC, CCRN, FAHA, is a professor in the Capstone College of Nursing, The University of Alabama, Tuscaloosa, Alabama. Email: sappel@ua.edu.
CDR Arnel J. Barba, MS, DNP, CRNA, NC, USN, is an active-duty CRNA in the United States Navy. Currently, he serves as an assistant professor in the Daniel K. Inouye Graduate School of Nursing, Uniformed Services University of the Health Sciences, Nurse Anesthesia Program, United States Navy, San Diego, California. Email: arnel.barba@usuhs.edu.

DISCLOSURES
The authors declare they have no financial relationships with any commercial entity related to the content of this article. The authors did not discuss off-label use within the article.

MILITARY DISCLAIMER
The views expressed here are the authors and do not necessarily reflect the official policy of the Department of the Navy, Department of Defense, or the U.S. Government.

ACKNOWLEDGMENTS
The authors gratefully acknowledge the support of the Anesthesia Department at the Naval Medical Center San Diego in San Diego, California, and the Capstone College of Nursing at The University of Alabama, Tuscaloosa, Alabama, for their assistance in making this project possible.

Author's Correction
In “Laryngeal Mask Airway and Valsalva Maneuver During Ophthalmic Surgery: A Case Report” in the December 2016 AANA Journal (Vol. 84, No. 6, p. 423), under “Case Summary” the patient is described as having “a left orbital socket defect requiring exoneration.” The word should be exenteration.