Research Article

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Economic analysis of the use of video laryngoscopy versus direct laryngoscopy in the surgical setting

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Aim: Compared with direct laryngoscopy (DL), video laryngoscopy (VL) offers clinical benefits in routine and difficult airways. The health economic benefit of VL versus DL for routine tracheal intubation remains unknown. **Materials & methods:** This analysis compared VL and DL health economic outcomes, including total inpatient costs, length of hospital stay (LOS), postoperative intensive care unit (ICU) admission and incidence of procedurally associated complications. **Results:** Patients with VL had decreased inpatient cost (US$1144–5891 across eight major diagnostic categories [MDC]); >1-day LOS reduction in five MDC; reduced odds for postoperative ICU admission (0.04–0.68) and reduced odds of respiratory complications in three MDC (0.43–0.90). **Conclusion:** Video laryngoscopy may lower total costs, reduce LOS and decrease the likelihood of postoperative ICU admission.

Lay abstract: In this study, we compared the difference in hospital cost, length of hospital stay, post-surgery complications and post-surgery intensive care unit (ICU) admission between two groups of patients. Both groups of patients were admitted to the hospital for a surgical procedure and underwent general anesthesia for at least 1 h. Before administering anesthesia for surgery, an anesthesiologist inserts a tube into the patient's airway to ventilate the patient. The anesthesiologist might use different types of laryngoscope to assist with the insertion of the tube. The choice of the laryngoscope type is based on several factors such as the availability of the device, doctor's experience, preference and patient's medical and physical conditions. This study focuses on two different types of laryngoscopes: the video laryngoscope and the direct laryngoscope. Patients who received video laryngoscope or direct laryngoscope were divided into separate groups. We made sure that these two groups of patients were comparable in terms of similar age, gender and disease conditions, stayed in similar types of hospitals and had similar procedures. Compared with the direct laryngoscope group, the video laryngoscope group had lower hospital costs (reduced by US$1144–5891), at least 1-day shorter length of hospital stay, reduced rates of ICU admission and fewer complications. This study indicates that video laryngoscopy offers benefits over direct laryngoscopy for elective surgical procedures.

Tweetable abstract: Video laryngoscopy is associated with reduced hospital cost, shorter length of stay, lower ICU admission rates and fewer complications compared with direct laryngoscopy. #videolaryngoscopy #healtheconomics.

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Keywords: direct laryngoscopy • health economic analysis • hospital cost • intensive care unit • length of stay • tracheal intubation • video laryngoscopy

Laryngoscopy and tracheal tube placement is a standard procedure with rare but potentially severe complications. In 2010, it was estimated that tracheal tubes were used during 15 million surgeries in USA [1]. Difficult and failed intubation occurs in fewer than 6% and 0.3% of cases, respectively, and is more likely to occur in the emergency or intensive care setting than in the operating room setting [2,3]. Though their incidence is relatively low, when

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complications associated with difficult and failed intubation occur, they can be irreversible and fatal [4]. In a US study, 2.3% of anesthesia-related deaths were due to failed or difficult intubation [5]. Consequently, identifying improvements to increase tracheal intubation's success and safety is a priority for hospitals.

The introduction of video laryngoscopy (VL) into clinical practice represents a significant advance. Unlike direct laryngoscopy (DL) that relies on a direct line of sight approach to the glottic opening, VL uses an indirect approach, transmitting images from the blade's tip for improved visualization of the glottic opening. Many studies have demonstrated that VL reduces the incidence of difficult intubation and is superior for patients with predicted difficult airways [3]. VL use is increasingly recommended in airway guidelines as a primary intubation technique and as a rescue approach when DL fails [6,7]. The majority of difficult intubation events are unexpected despite adequate assessment [4,8,9]. Therefore, the potential value of using VL as a first-line approach is a meaningful discussion [10–14].

This retrospective cohort study was conducted to analyze clinical and economic outcomes of VL versus DL in a cohort of patients in the operating room setting. The study used the Premier Healthcare Database, representing about 25% of annual US inpatient admissions each year. It includes many patients, types of surgical procedures and hospital environments, making it a rich resource to compare outcomes of different procedures like DL and VL. The findings could be informative to clinicians contemplating whether VL should be considered over DL as a primary alternative for tracheal intubation.

Materials & methods

Study design

We conducted a retrospective observational cohort study using 3 years of data (2016–2018) from the Premier Healthcare Database. The Premier Healthcare Database is considered exempt from Institutional Review Board oversight as dictated by Title 45 Code of Federal Regulations, Part 46 of the US, specifically 45 CFR 46.101(b)(4). In accordance with the Health Insurance Portability and Accountability Act Privacy Rule, disclosed data from Premier are considered de-identified per 45 CFR 164.506(d)(2)(ii)(B) through the 'Expert Determination' method.

Cohort selection

All adult patients who underwent elective surgery in the inpatient setting with at least 1 h of general anesthesia and tracheal intubation (having a keyword of 'intubation' in charge master file) were queried (n = 72,284, Figure 1). The requirement for 1 h of general anesthesia was intended to exclude patients who underwent minor surgical procedures. Emergency cases and pregnant patients were excluded because clinical approaches and patient conditions might differ substantially from elective surgical populations. Patients were stratified into 25 major diagnostic categories (MDC) based on their diagnosis-related group (DRG). The final cohort included adult patients in the top ten MDC groups, which accounted for 86.2% of the adult elective surgical patients (n = 62,297/72,284, Figure 1).

Based on the type of laryngoscope used for intubation, the cohort was separated into DL and VL groups. A keyword search from the charge master file was used to identify the laryngoscope (DL vs VL). Keywords included the combination of the manufacturer's name, blade name, size, type and the phrases 'video laryngoscopy' or 'direct laryngoscopy' and their abbreviations (Supplementary Table 1). A reimbursement expert reviewed the list of keywords and confirmed the accuracy of categorization. Patients who had no record of the type of laryngoscopy used were assigned to the DL group. This was performed because DL was frequently bundled in overall anesthesia reporting and therefore was underreported. There were significantly more patients undergoing DL compared with those receiving VL in our cohort (n = 55,320 vs 6799). Therefore, patients receiving DL were randomly selected within each MDC group at a ratio of 3:1 (DL: VL), to mitigate the sample size imbalance between groups while maintaining the patient and hospital characteristics of the original DL group [15,16]. In the Ear, Nose, Mouth, and Throat disease MDC group, the ratio was 2:1 DL: VL because the DL group was too small to generate a 3:1 ratio.

Sensitivity analysis

To ensure that the differences between the groups were not due to the misclassification of patients that underwent DL, a sensitivity analysis was performed. In this analysis, the restriction of 1 h of surgery time was removed to include more DL cases. A propensity matching method was used to balance the patient's clinical and hospital characteristics between DL and VL groups on each MDC level. One patient in the DL group had a prolonged hospital stay (472 days) and was excluded from the analysis. This patient had a neurologic condition and epilepsy

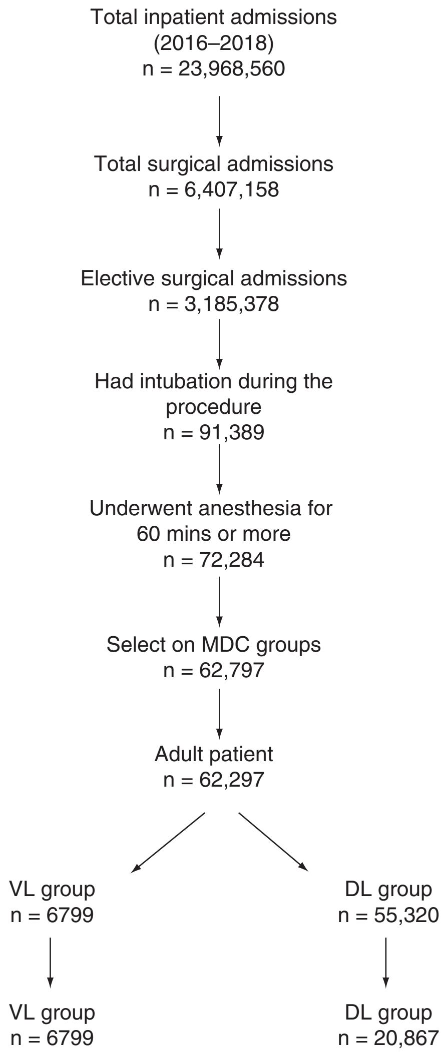

Figure 1. Flow chart of patient inclusion. Diagram showing the criteria applied to arrive at the final patient cohort. To adjust for sample size imbalance between the DL and VL groups, patients were randomly selected at a 3:1 ratio DL:VL for each MDC, with the exception of the Diseases and Disorders of the Ear, Nose, Mouth and Throat group, in which a 2:1 DL:VL ratio was used because there were too few patients in the DL group to select at a 3:1 ratio.
DL: Direct laryngoscopy; MDC: Major disease category; VL: Video laryngoscopy.

(primary ICD_10 diagnosis code: G40.909), and on hospital day #123 underwent a tracheotomy and placement of a tracheostomy device (ICD_10 surgical procedure code: 0B110F4).

Outcome measures

Primary outcomes included total inpatient costs, length of hospital stay (LOS), postoperative intensive care unit (ICU) admission rate and relevant postoperative complications. Postoperative ICU admission was defined as patients admitted to the ICU on or after the day of surgery. Postoperative complications were identified using ICD-10 codes for pulmonary infection (J15, J18), cardiovascular complications (I20, I21, I24, I46), respiratory complications (J98.1, J95.89) and other complications of surgical medical care (T88) (Supplementary Table 2).

Statistical analysis

Univariate analysis was used to compare baseline patient demographics, clinical characteristics and hospital characteristics. Chi-square test or Fisher's exact test was used for categorical variables and the Wilcoxon test for continuous variables. p-values were two-tailed with statistical significance set at $p < 0.05$.

The adjusted inpatient cost difference was estimated using a generalized estimating equation (GEE) model with gamma distribution. The adjusted length of stay difference was estimated using a GEE model with the Poisson distribution. Multivariable logistic regressions were performed to estimate the difference in postoperative ICU rate and complication rate. Since complication rates are rare, Firth's penalized likelihood approach was used to reduce small-sample bias in maximum likelihood estimation in logistic regression models. All models controlled for patient baseline characteristics, including patient age, gender, race, marital status, Charlson comorbidity index and primary insurance, and hospital characteristics, including teaching hospital status, bed size, hospital regions and location. All statistical analyses were performed using SAS Version 9.4 (SAS Institute Inc., NC, USA).

Results

Patient & hospital characteristics

A total of 62,297 patients met the study selection criteria. After the 1:3 (VL: DL) random selection from the DL group (1:2 VL: DL for the Diseases of the Ear, Nose, Mouth and Throat MDC group), the final cohort consisted of 6799 patients receiving VL and 20,867 patients receiving DL (Figure 1).

Patient demographics and clinical characteristics, and hospital characteristics of patients in the VL and DL groups, are shown in Table 1. Compared with the DL group, patients who received VL were slightly younger (average age 60.9 years vs 61.5 years, p = 0.0007), more likely to be male (52.5% [n = 3666/6977] vs 45.1% [n = 9412/20,867], p < 0.0001) and Caucasian (80.4% [n = 5609/6977] vs 76.2% [n = 15,902/20,867], p < 0.0001). Compared with the DL group, patients in the VL group were more likely to be admitted to hospitals that were rural and were teaching institutions (18.9% [n = 1321/6977] vs 11.8% [n = 2463/20,867], p < 0.0001 and 42.6% [n = 2972/6977] vs 28.9% [n = 6038/20,867], p < 0.0001, respectively), and that were in the Midwest and West regions (26.1% [n = 1820/6977] vs 5.3% [n = 1101/20,867], p < 0.0001 and 24.8% [n = 1731/6977] vs 7.2% [n = 1506/20,867], p < 0.0001, respectively). The average anesthesia time was longer in the VL group (227 min vs 218 min, p < 0.0001). The distribution of patients across MDC groups was similar between the VL and DL groups (p = 0.6122).

Total inpatient cost

After controlling for patient demographic and clinical and hospital characteristics, compared with the DL group, the VL group had a significantly lower average total inpatient cost in eight out of ten MDC groups (Figure 2A). The cost difference between the VL and DL groups ranged from $1144 to $5891 across the eight MDC groups. The MDC groups with the lowest and the highest savings in average total inpatient costs were the Diseases and Disorders of the Male Reproductive System group ($13,930 vs $15,074, p < 0.032), and Diseases and Disorders of the Ear, Nose, Mouth and Throat group ($13,485 vs $19,376, p < 0.0001), respectively. No difference was observed in average total inpatient costs between VL and DL groups in the Diseases and Disorders of the Circulatory System MDC group ($45,594 vs $44,155, p = 0.1758).

In the unadjusted analysis, compared with the DL group, the VL group had a significantly lower average inpatient cost in three out of ten MDC groups (Figure 2B). These were the diseases and disorders of the digestive system ($21,021 vs $24,121, p = 0.0007), the diseases and disorders of the respiratory system ($25,848 vs $31,979, p = 0.0005), and the diseases and disorders of the ear, nose, mouth and throat ($15,886 vs $21,060, p = 0.017) MDC groups. The unadjusted average inpatient cost was higher in the VL group compared with the DL group in two of the MDC groups; the diseases and disorders of the male reproductive system ($13,891 vs $11,970, p = 0.0019) and the diseases and disorders of the female reproductive system ($14,367 vs $12,041, p = 0.003).

Length of stay

After controlling for patient demographic and clinical and hospital characteristics, compared with the DL group, the VL group had a shorter adjusted average hospital LOS across nine of the ten MDC groups. The average LOS difference was statistically significant in eight out of ten MDC groups (Figure 3A). The reduction in average LOS was greater than 1 day in five of the MDC groups, including diseases and disorders of the ear, nose, mouth and throat (3.2 days vs 4.6 days, p < 0.0001), and diseases and disorders of the digestive system (8.0 days vs 9.4 days, p < 0.0001).

The unadjusted average LOS was significantly shorter in the VL group in two of the ten MDC groups, diseases and disorders of the musculoskeletal system and connective tissue (2.8 vs 3.0 days, p = 0.0011) and diseases and disorders of the digestive system (6.0 vs 7.0 days, p = 0.0004). There was no statistically significant difference in unadjusted average LOS for the rest of the MDC groups (Figure 3B).

Postoperative ICU rate

Among postoperative ICU admissions, 90.1% (n = 878/975), and 87.4% (n = 3077/3521) occurred within 1 day of the surgical procedure in the VL and DL groups, respectively.

Table 1. Patient and hospital characteristics.

Patient demographic characteristics	Video laryngoscopy (n = 6977) Mean (SD)	Direct laryngoscopy (n = 20,867) Mean (SD)	p-value
Age (years)	60.9 (12.9)	61.5 (13.7)	0.0007
	n (%)	n (%)	
Gender			<0.0001
– Female	3311 (47.5%)	11,455 (54.9%)	
– Male	3666 (52.5%)	9412 (45.1%)	
Marital status			<0.0001
– Married	4193 (60.1%)	12,633 (60.5%)	
– Single	2537 (36.4%)	7918 (37.9%)	
– Other	247 (3.5%)	316 (1.5%)	
Race			<0.0001
– Caucasian	5609 (80.4%)	15,902 (76.2%)	
– African–American	688 (9.9%)	3502 (16.8%)	
– Other	621 (8.9%)	1356 (6.5%)	
– Unknown	59 (0.8%)	107 (0.5%)	
Insurance type			<0.0001
– Government	4135 (59.3%)	11,566 (55.4%)	
– HMO/commercial	2403 (34.4%)	7094 (34.0%)	
– Other	371 (5.3%)	1955 (9.4%)	
– Self-insured	68 (1.0%)	252 (1.2%)	
Patient clinical characteristics	Mean (SD)	Mean (SD)	
Total anesthesia time, min	227 (130.9)	218 (188.5)	<0.0001
	n (%)	**n (%)**	
Charlson comorbidity index			0.044
– 0	2795 (40.1%)	8653 (41.5%)	
– 1–2	2771 (39.7%)	7936 (38.0%)	
– 3–4	850 (12.2%)	2497 (12.0%)	
– 5 and above	561 (8.0%)	1781 (8.5%)	
Major diagnostic category (MDC), diseases and disorders of:			0.612
– Ear, nose, mouth and throat	68 (1.0%)	137 (0.7%)	
– Respiratory system	212 (3.0%)	636 (3.0%)	
– Circulatory system	656 (9.4%)	1968 (9.4%)	
– Digestive system	825 (11.8%)	2475 (11.9%)	
– Hepatobiliary system and pancreas	122 (1.7%)	367 (1.8%)	
– Musculoskeletal system and connective tissue	3725 (53.4%)	11,176 (53.6%)	
– Endocrine, nutritional and metabolic system	582 (8.3%)	1747 (8.4%)	
– Kidney and urinary tract	265 (3.8%)	795 (3.8%)	
– Male reproductive system	151 (2.2%)	453 (2.2%)	
– Female reproductive system	371 (5.3%)	1113 (5.3%)	
Hospital characteristics	n (%)	n (%)	
Hospital location			<0.0001
– Rural	1321 (18.9%)	2463 (11.8%)	
– Urban	5656 (81.1%)	18,404 (88.2%)	
Teaching hospital			<0.0001
– No	4005 (57.4%)	14,829 (71.1%)	
– Yes	2972 (42.6%)	6038 (28.9%)	
Bed size			<0.0001
– 000–299	2929 (42.0%)	6235 (29.9%)	

Values are reported as mean (SD) or number (proportion).
Chi-square test was used for categorical variables and the Student's t-test for continuous variables.
DL: Direct laryngoscope; MDC: Major diagnostic category; SD: Standard deviation; VL: Video laryngoscope.

Table 1. Patient and hospital characteristics (cont.).

Patient demographic characteristics	Video laryngoscopy (n = 6977) Mean (SD)	Direct laryngoscopy (n = 20,867) Mean (SD)	p-value
– 300–499	2112 (30.3%)	10,286 (49.3%)	
– 500+	1936 (27.7%)	4346 (20.8%)	
Hospital region			<0.0001
– Midwest	1820 (26.1%)	1101 (5.3%)	
– Northeast	487 (7.0%)	1097 (5.3%)	
– South	2939 (42.1%)	17,163 (82.2%)	
– West	1731 (24.8%)	1506 (7.2%)	

Values are reported as mean (SD) or number (proportion).
Chi-square test was used for categorical variables and the Student's t-test for continuous variables.
DL: Direct laryngoscope; MDC: Major diagnostic category; SD: Standard deviation; VL: Video laryngoscope.

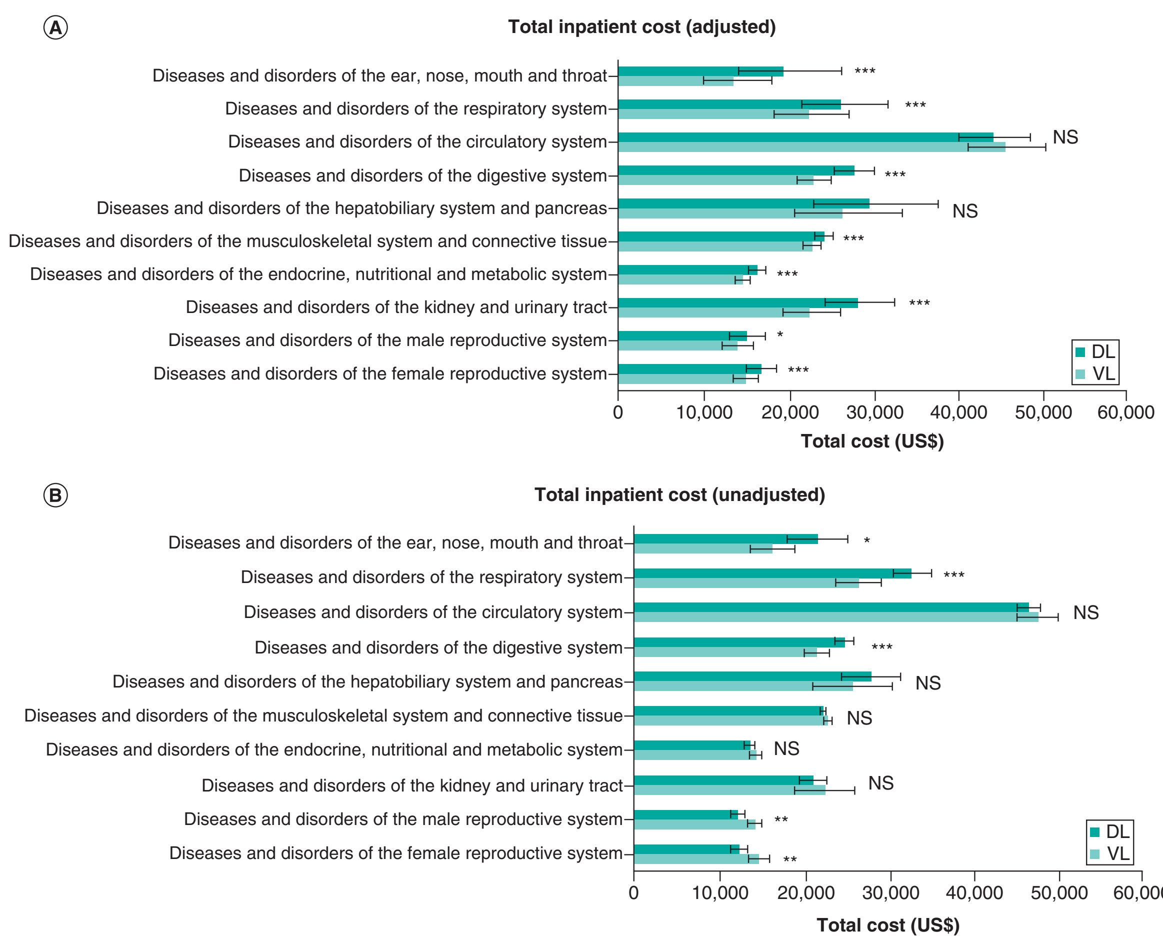

Figure 2. Total inpatient cost. (A) Adjusted average total inpatient cost for patients receiving DL and VL in each major disease category (MDC), using a GEE model with gamma distribution to adjust for differences in baseline patient and hospital characteristics. Average total inpatient cost and 95% CI are shown. **(B)** Observed (unadjusted) average total inpatient cost for DL and VL patients in each MDC group. Average cost and standard deviation are shown. No mark, not significant ($p \geq 0.05$). VL (filled bars); DL (open bars).
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
DL: Direct laryngoscopy; MDC: Major disease category; VL: Video laryngoscopy.

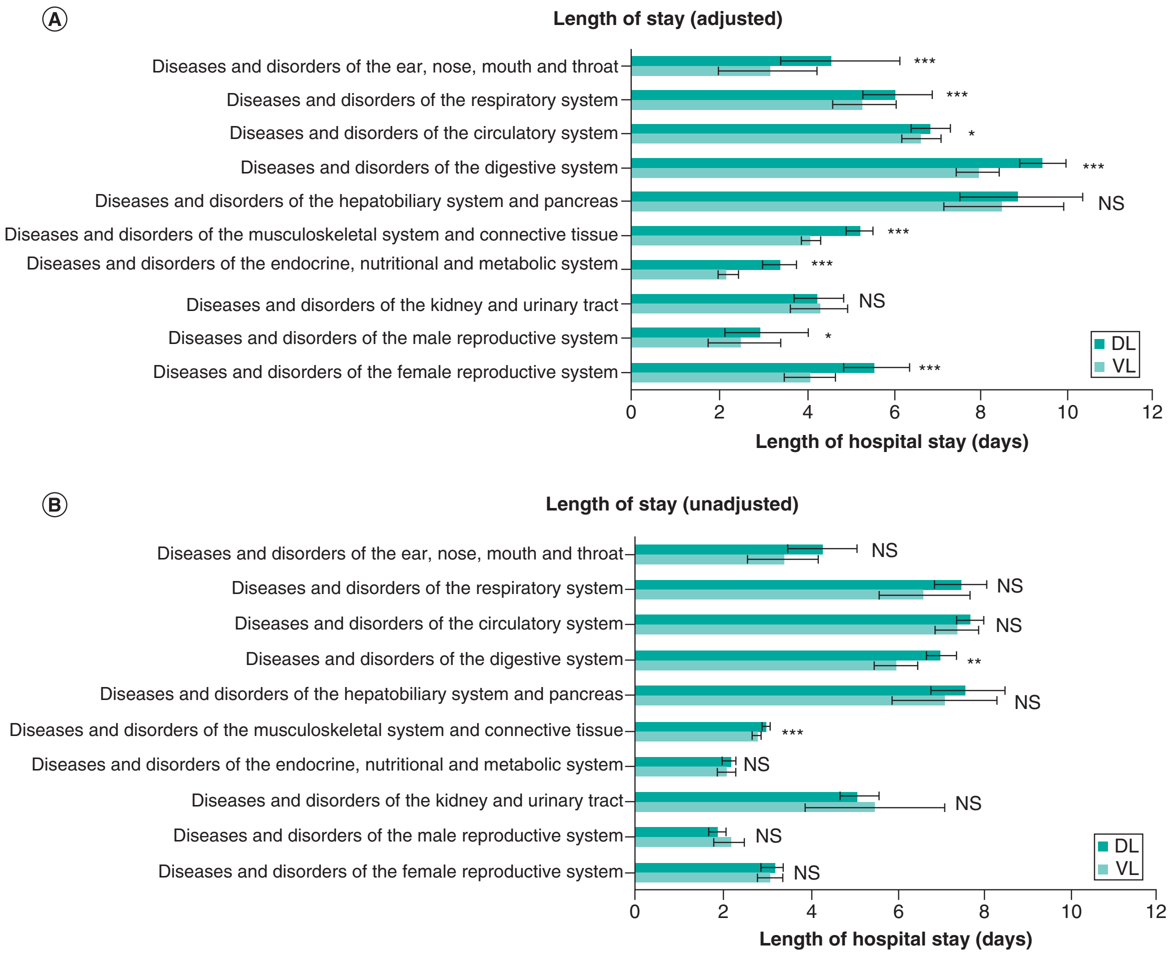

Figure 3. Total hospital length of stay. (A) LOS for each MDC group, using a GEE model with Poisson distribution to adjust for differences in baseline patient and hospital characteristics. Average LOS and 95% CI are shown. **(B)** Observed (unadjusted) hospital length of stay for patients receiving DL and VL in each MDC group. Average LOS and standard deviation are shown. No mark, NS ($p \geq 0.05$). VL (filled bars); DL (open bars).
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
DL: Direct laryngoscopy; LOS: Length of hospital stay; MDC: Major disease category; NS: Not significant; VL: Video laryngoscopy.

After controlling for patient demographics and clinical and hospital characteristics, the likelihood of postoperative ICU admission was significantly lower ($p < 0.05$) for the VL group than the DL group in all ten MDC groups. The adjusted odds ratio of postoperative ICU admission ranged from 0.04 to 0.68 (Table 2).

The unadjusted average postoperative ICU admission rate was lower with VL than DL across six of the ten MDC groups. The admission rate difference ranged from 0.8 to 25.5%, with the largest difference seen in the diseases and disorders of the ear, nose, mouth and throat group (VL vs DL, 17.6% [n = 12/68], vs 43.1% [n = 59/137], p = 0.0003). No difference in the average postoperative ICU admission rate was observed in the remaining four MDC groups (Table 3).

Complications

After controlling for patient demographics and clinical and hospital characteristics, the likelihood of experiencing perioperative complications was lower with VL compared with DL in several MDC groups. Comparing patients receiving VL to patients receiving DL, the likelihood of having pulmonary infection was lower in three MDC groups, including the diseases and disorders of the: digestive system; musculoskeletal system and connective tissue; and endocrine, nutritional and metabolic system (OR: 0.56, OR: 0.49 and OR: 0.30; p = 0.03123, p = 0.02996, and p = 0.00441, respectively); having cardiovascular complications was lower in six MDC groups, including diseases

Table 2. Adjusted odds ratio for postoperative intensive care unit (direct laryngoscopes as reference).

Major disease categories	Odds ratio (95% LCL, 95% UCL)
Ear, nose, mouth and throat	0.166 (0.066, 0418)
Respiratory system	0.680 (0.475, 0.974)
Circulatory system	0.573 (0.455, 0.721)
Digestive system	0.235 (0.176, 0.315)
Hepatobiliary system and pancreas	0.276 (0.139, 0.547)
Musculoskeletal system and connective tissue	0.323 (0.258, 0.404)
Endocrine, nutritional and metabolic system	0.503 (0.309, 0.819)
Kidney and urinary tract	0.347 (0.212, 0.569)
Male reproductive system	0.152 (0.038, 0.618)
Female reproductive system	0.042 (0.016, 0.111)

Values are reported as odds ratio (lower–upper confidence limit).
ICU: Intensive care unit; LCL: Lower confidence limit; UCL: Upper confidence limit.

Table 3. Postoperative intensive care unit admission rate.

Major disease categories	Video laryngoscopy (%)	Direct laryngoscopy (%)	p-value
Ear, nose, mouth and throat	12/68 (17.6)	59/137 (43.1)	0.0003
Respiratory system	100/212 (47.2)	332/636 (52.2)	0.204
Circulatory system	472/656 (72.0)	1531/1968 (77.8)	0.002
Digestive system	92/825 (11.2)	567/2475 (22.9)	0.0001
Hepatobiliary system and pancreas	25/122 (20.5)	132/367 (36.0)	0.0015
Musculoskeletal system and connective tissue	166/3725 (4.5)	597/11,176 (5.3)	0.034
Endocrine, nutritional and metabolic system	46/582 (7.9)	121/1747 (6.9)	0.429
Kidney and urinary tract	44/265 (16.6)	159/795 (20.0)	0.224
Male reproductive system	7/151 (4.6)	23/453 (5.1)	0.829
Female reproductive system	11/371 (3.0)	83/1113 (7.5)	0.002

Values are reported as number (proportion).
ICU: Intensive care unit.

and disorders of the: respiratory system; digestive system; musculoskeletal system and connective tissue; endocrine, nutritional and metabolic system diseases; kidney and urinary track; and female reproductive system (OR: 0.28, OR: 0.3, OR: 0.21, OR: 0.12, OR: 0.11 and OR: 0.12; $p = 0.00705$, $p = 0.00018$, $p = 0.00375$, $p < 0.0001$, $p = 0.00268$ and $p = 0.007$, respectively); having respiratory complications was lower in three MDC groups, including diseases and disorders of the: circulatory system; hepatobiliary system and pancreas; and endocrine, nutritional and metabolic system (OR: 0.66, OR: 0.90 and OR: 0.43, $p = 0.00415$, $p < 0.0001$ and $p = 0.03245$, respectively); having other surgical/medical care complications was lower in one MDC group, diseases and disorders of the hepatobiliary system and pancreas (OR: 0.9, $p < 0.0001$) and higher in one MDC group, diseases and disorders of the female reproductive system (OR: 16.04, $p = 0.00141$; Table 4).

In the diseases and disorders of the circulatory system MDC group, the unadjusted rate of respiratory complications was significantly lower in the VL group compared with the DL group (10.8% [n = 71/656], vs 15.5% [n = 305/1968], $p = 0.003$). In the diseases and disorders of the digestive system MDC group and the musculoskeletal system and connective tissue MDC group, the unadjusted rate of cardiovascular complications was significantly lower in the VL group compared with the DL group (1.3% [n = 11/825], vs 3.7% [n = 91/2475], $p = 0.008$; and 0.6% [n = 27/3725], vs 1.2% [n = 137/11,176], $p = 0.003$, respectively). There were no other significant differences in unadjusted complication rates between the VL and DL groups with the other MDC groups (Table 5).

Sensitivity analysis

A total of 88 DL cases and 264 VL cases were included in the sensitivity analysis. The range of LOS was 1–106 days for the VL group, and 1–71 days for the DL group, across ten MDC groups. The VL group had shorter average hospital LOS (11.2 vs 14.7 days, $p = 0.049$), and lower average postoperative ICU admission rate (49.2% [n = 130/264], vs 61.4% [n = 54/88], $p = 0.049$) compared with the DL group. The average total inpatient cost

Table 4. Adjusted odds ratio for selected complications (direct laryngoscopes as reference).

Major disease categories	Pulmonary infection	Cardiovascular complication	Respiratory complication	Other surgical/medical care complication
Diseases and disorders of:	Odds ratio (95% LCL, 95% UCL)			
Ear, nose, mouth and throat	0.18 (0.03, 1.17)	0.34 (0.06, 1.99)	0.85 (0.81, 4.04)	0.69 (0.12, 4.11)
Respiratory system	0.83 (0.50, 1.37)	0.28 (0.11, 0.71)	0.89 (0.56, 1.43)	1.30 (0.42, 4.00)
Circulatory system	1.09 (0.73, 1.62)	1.05 (0.77, 1.42)	0.66 (0.50, 0.88)	0.38 (0.10, 1.40)
Digestive system	0.56 (0.33, 0.95)	0.3 (0.16, 0.56)	0.76 (0.53, 1.10)	1.74 (0.60, 5.11)
Hepatobiliary system and pancreas	1.02 (1.00, 1.04)	0.55 (0.17, 1.75)	0.9 (0.88, 0.91)	0.9 (0.88, 0.91)
Musculoskeletal system and connective tissue	0.49 (0.30, 0.89)	0.21 (0.13, 0.33)	0.92 (0.65, 1.3)	0.61 (0.25, 1.46)
Endocrine, nutritional and metabolic system	0.30 (0.10, 0.89)	0.12 (0.03, 0.50)	0.43 (0.20, 0.93)	0.80 (0.22, 2.97)
Kidney and urinary tract	0.62 (0.25, 1.55)	0.11 (0.03, 0.46)	0.75 (0.40, 1.42)	3.06 (0.73, 12.74)
Male reproductive system	0.99 (0.18, 5.6)	0.65 (0.12, 3.36)	1.73 (0.31, 9.55)	0.96 (0.21, 4.34)
Female reproductive system	0.47 (0.15, 1.47)	0.12 (0.02, 0.56)	0.79 (0.30, 2.08)	16.04 (2.92, 88.13)

Values are reported as odds ratio (lower–upper confidence limit).
LCL: Lower confidence limit; UCL: Upper confidence limit.

was lower in the VL group compared with the DL group, although the difference was not statistically significant (\$56,384 vs \$57,287, $p = 0.913$). There were no statistically significant differences in complication rates between VL and DL (Table 6).

Discussion

Laryngoscopy for tracheal intubation is infrequently associated with complications, but when complications do occur, they can be severe, fatal and irreversible. Difficult and failed intubations are associated with adverse outcomes, including hypoxemia, bronchospasm, airway trauma, hypertension, arrhythmias, cardiac arrest, neurologic damage, unplanned ICU admission and death [4,17]. Rates of difficult and failed intubation have decreased in recent years as newer guidelines and devices have been introduced into clinical practice [18]. It is essential to continue efforts to maximize the safety of laryngoscopy and tracheal intubation.

Multiple studies have demonstrated that VL provides a better glottic view and reduces the number of failed intubation attempts compared with DL [3]. A 2016 Cochrane review of 38 trials involving 4127 participants concluded that VL significantly reduced the frequency of failed intubations compared with DL [3]. The decreased incidence of failed intubations was particularly significant in studies of patients with anticipated or simulated difficult airways [3]. VL is recommended in several airway guidelines [7,19,20], and it is commonly used and has shown a high success rate when used as a rescue approach after DL failure [6,11,21]. However, despite efforts to identify potential difficult airways before intubation, most difficult intubations are unanticipated [4,8,9,22]. This suggests a potential benefit to utilizing VL even when difficult intubation has not been anticipated [10,11]. VL is increasingly recommended and used as part of the first-line strategy in routine intubation cases [10,13,23,24], and there is evidence supporting its benefits in patients with non-difficult airways [25].

Little is understood about the impact of VL and DL on health economic outcomes for patients undergoing inpatient elective surgical procedures. A study conducted by Alsumali and colleagues using a simulated decision tree model found that VL was associated with a reduction of adverse events and there was \$3429 saved per adverse event avoided in the operating room setting [26]. Another retrospective cohort study by Moucharite and colleagues showed difficult and failed intubations are also associated with higher inpatient cost and longer LOS [27]. The goal of the present study was to analyze real-world data from the Premier Healthcare Database, representing approximately 25% of all US inpatient admissions, to fill this gap. This large sample size allows sufficient power for the study of uncommon tracheal intubation-related complications. Since procedure complexity, cost and patient outcomes are expected to differ significantly among MDC groups, the analysis was strengthened by carrying out comparisons at the MDC group level. MDC groups were formed by dividing all possible principal diagnoses into 25 mutually exclusive principal diagnosis areas. The diagnoses in each MDC correspond to a single-organ system or etiology and in general are associated with a particular medical specialty. Clinical care is generally organized in accordance

Table 5. Complications by major disease categories.

Complications	Video laryngoscopy (n)	Direct laryngoscopy (n)	p-value
Ear, nose, mouth and throat, n (%)	68	137	
– Pulmonary infection	0 (0.0)	5 (3.7)	0.173†
– Cardiovascular complication	0 (0.0)	4 (2.9)	0.304†
– Respiratory complication	1 (1.5)	2 (1.5)	1†
– Other surgical/medical care complications	0 (0.0)	2 (1.5)	1†
Respiratory system, n (%)	212	636	
– Pulmonary infection	25 (11.8)	78 (12.3)	0.856
– Cardiovascular complication	5 (2.4)	38 (6.0)	0.045†
– Respiratory complication	28 (13.2)	96 (15.1)	0.501
– Other surgical/medical care complications	2 (0.9)	6 (0.9)	1†
Circulatory system, n (%)	656	1968	
– Pulmonary infection	41 (6.3)	97 (4.9)	0.189
– Cardiovascular complication	72 (11.0)	200 (10.2)	0.554
– Respiratory complication	71 (10.8)	305 (15.5)	0.003
– Other surgical/medical care complications	1 (0.2)	11 (0.6)	0.315†
Digestive system, n (%)	825	2475	
– Pulmonary infection	18 (2.2)	87 (3.5)	0.059
– Cardiovascular complication	11 (1.3)	91 (3.7)	0.008
– Respiratory complication	44 (5.3)	156 (6.3)	0.321
– Other surgical/medical care complications	3 (0.4)	4 (0.2)	0.377†
Hepatobiliary system and pancreas, n (%)	122	367	
– Pulmonary infection	10 (8.2)	26 (7.1)	0.684
– Cardiovascular complication	3 (2.5)	17 (4.6)	0.430†
– Respiratory complication	8 (6.6)	26 (7.1)	0.843
– Other surgical/medical care complications	0 (0.0)	0 (0.0)	NA
Musculoskeletal system and connective tissue, n (%)	3725	11,176	
– Pulmonary infection	26 (0.7)	90 (0.8)	0.519
– Cardiovascular complication	27 (0.6)	137 (1.2)	0.003†
– Respiratory complication	68 (1.8)	181 (1.6)	0.396
– Other surgical/medical care complications	8 (0.2)	15 (0.1)	0.333†
Endocrine, nutritional and metabolic system, n (%)	582	1747	
– Pulmonary infection	3 (0.5)	16 (0.9)	0.436†
– Cardiovascular complication	1 (0.2)	17 (1.0)	0.056†
– Respiratory complication	9 (1.6)	27 (1.6)	1†
– Other surgical/medical care complications	1 (0.2)	4 (0.2)	1†
Kidney and urinary tract, n (%)	265	795	
– Pulmonary infection	5 (1.9)	27 (3.4)	0.214
– Cardiovascular complication	1 (0.4)	31 (3.9)	0.002†
– Respiratory complication	16 (6.0)	43 (5.4)	0.699
– Other surgical/medical care complications	1 (0.4)	2 (0.3)	1†
Male reproductive system, n (%)	151	453	
– Pulmonary infection	1 (0.7)	1 (0.2)	0.438†
– Cardiovascular complication	1 (0.7)	4 (0.9)	1†
– Respiratory complication	1 (0.7)	3 (0.7)	1†
– Other surgical/medical care complications	1 (0.7)	1 (0.2)	0.348†
Female reproductive system, n (%)	371	1113	
– Pulmonary infection	4 (1.1)	11 (1.0)	1†
– Cardiovascular complication	1 (0.3)	12 (1.1)	0.205†
– Respiratory complication	7 (1.9)	23 (2.1)	1†
– Other surgical/medical care complications	2 (0.5)	0 (0.0)	0.62†

Values are reported as number (proportion).
†Indicates Fisher's exact test.

Table 6. Overall cost, observed and adjusted for confounding factors.

End point	Video laryngoscopes (n = 264)	Direct laryngoscopes (n = 88)	p-value
Overall cost, US$, mean (SD)	$56,384 ($87,696)	$57,278 ($57,518)	0.913
Length of stay, days, mean (SD)	11.2 (14.8)	14.7 (14.0)	0.049
Postoperative ICU, n (%)	130 (49.2)	54 (61.4)	0.049
Pulmonary infection, n (%)	36 (13.6)	116 (12.5)	0.786
Cardiovascular complications, n (%)	20 (7.6)	7 (8.0)	0.908
Respiratory complications, n (%)	33 (12.5)	10 (11.4)	0.778
Other surgical medical care complications n (%)	2 (0.8)	0 (0.0)	0.413

Values are reported as mean (SD) or number (proportion).
ICU: Intensive care unit; N: Number; SD: Standard Deviation.

with the organ system affected. Using MDC groups helped us limit the number of surgical procedures included without limiting the analysis to specific surgery types.

When comparing patient and hospital characteristics between patients receiving DL or VL, we observed several significant differences. Patients who were younger, male or Caucasian were more likely to receive VL, and patients at teaching hospitals or in the Midwest or West US regions were more likely to receive VL. The differences in use of VL likely reflect not only differences in the need to utilize VL on specific patients, but could also reflect more rapid adoption of newer technology and training depending on the teaching capabilities of the hospital and its regional location. Similarly, differences in VL use across ethnicities may reflect differences in individual preferences and hospital characteristics, including size, region and teaching capabilities. In addition to controlling for a range of patient and hospital characteristics, the multivariate analysis controlled for anesthesia time, a potential marker of complexity.

This study showed improved health economic outcomes with VL compared with DL in patients undergoing elective surgery in the inpatient setting and confirmed the findings of Alsumali *et al.* [26]. The average total inpatient costs were significantly lower for patients treated with VL than DL in eight out of ten MDC groups. The cost savings per inpatient event ranged from $1144 to $5891, depending on the MDC group. The reduced costs may reflect improved patient outcomes, as VL was also associated with shorter average hospital LOS, with average stays being reduced to more than 1 day in half of the MDC groups. Notably, the likelihood of postoperative admission to the ICU was significantly lower for VL than DL across all ten MDC groups. VL was also associated with a lower likelihood of cardiovascular and respiratory complications in six and three of ten MDC groups, respectively. Overall, this analysis suggests a general benefit to using VL for elective surgical procedures in the inpatient setting, reflected in reduced costs, shorter LOS and reduced likelihood of complications and postoperative ICU admission.

We recognize several limitations of the study. First, it is a retrospective review of data used for administrative purposes, billing and reimbursement. There are no CPT/HCPCS or ICD-10 surgical procedure codes to directly identify the intubation method used during all surgical procedures. The keyword search approach may have failed to identify all patients because of the incompleteness of the keyword list or hospital under-reporting of terms due to the bundled payment of routine clinical practices. In this study, we found that DL procedures were significantly under-reported. The inclusion of patients in the DL group whose hospital billing line did not specify laryngoscopy type may have resulted in the misclassification of some patients receiving VL as DL, resulting in a heterogeneous DL group and making differences between groups more difficult to detect. We conducted a sensitivity analysis using confirmed VL and DL cases to address this limitation, which resulted in similar findings. It is also possible that some patients with prevailing airway conditions that could benefit from VL actually received DL, potentially increasing the likelihood, as well as the variance in occurrence, of postoperative complications in the DL group. Importantly, our analysis of an administrative database relies on real-world data, with patients receiving hospital standard of care. Therefore, the lower occurrence of complications in patients with VL observed in this study reflects the real-world circumstances that occur in the surgical setting, regardless of whether VL should be used in specific patient cases with prevailing airway conditions. In addition, although we stratified patients by MDC group, each MDC group includes a broad array of procedures that could impact patient outcomes, length of stay and costs. Our analysis is focused on the average patient in each MDC group, as opposed to specific procedure scenarios, in which there could be significant variability in healthcare outcomes. Future prospective studies might overcome this limitation. Future studies could also explore when and why VL is chosen over DL, including how often VL is available for anesthetists to use.

Another limitation is that the database contained no information about some aspects of the intubation procedure itself, such as the number of attempts, intubation time, or first attempt success rate, which could influence patient outcomes. An attempt to use ICD-10 diagnosis codes to identify soft tissue and teeth damage and difficult intubation found a very low incidence of reported data, which may be attributable to incomplete capturing and coding (data not shown). The database did not account for patient risk factors for difficult tracheal intubation such as degree of mouth opening, Mallampati class, thyromental distance and neck movement, which could influence the physician's intubation plan and impact patient outcomes. The administrative database also did not include patient medical information such as ASA classification, making evaluation of patient medical factors out of scope of the current analysis. Finally, assessment of the long-term effects of intubation methods was beyond the scope of this study. The influence of VL versus DL on long-term patient healthcare utilization or quality of life, which are impacted by brain damage or the incidence of aspiration pneumonia caused by difficult intubation, is worth future exploration.

Conclusion

In conclusion, this analysis suggests that there may be improvements in health economic outcomes using VL compared with DL across multiple MDC groups. Although we cannot draw a definite conclusion until further prospective studies are completed, the results indicate VL may be preferable to DL for elective surgical procedures in the inpatient setting. This analysis also highlights the need for proper documentation of laryngoscopy approaches, since approximately 10% of cases specified in the billing details whether VL or DL was used, and fewer than 0.15% specified when DL was used. We recommend that clinicians and EMR systems increase their efforts to document laryngoscopy information, including method, number of intubation attempts and success–failure with first intubation attempt in order to facilitate future studies comparing laryngoscopy methods.

Summary points

- Although there are well-established clinical benefits of video laryngoscopy (VL) over direct laryngoscopy (DL) in the operating room, the health economic outcomes of VL versus DL have not been described.
- This retrospective study compared total inpatient costs, length of hospital stay (LOS), postoperative intensive care unit (ICU) admission rate and complication rates between patients who received VL versus DL in the operating room for surgical procedures.
- The analysis controlled for differences in patient demographics and clinical characteristics, as well as hospital characteristics and procedure type by comparing patients within the same major diagnostic categories (MDC).
- In the adjusted cohort, inpatient cost for VL was significantly lower than DL in eight out of ten MDC groups, with a cost difference between $1144 to $5891 between VL and DL groups.
- Compared with the DL group, average LOS was significantly lower in the VL group in eight of ten MDC groups, with five MDC groups with a >1 day LOS reduction for patients in the VL group.
- The likelihood of postoperative ICU admission was significantly lower across all ten MDC groups, for the VL group versus the DL group.
- Complication rates for pulmonary infection, cardiovascular complications and respiratory complications, were lower in the VL group versus the DL group in multiple MDC groups.
- Overall, this study suggests that health economic outcomes are improved in patients receiving VL versus DL in the inpatient surgical setting, suggesting a benefit of utilizing VL for elective surgical procedures.
- Prospective analyses to compare health economic outcomes in patients receiving VL versus DL are needed to confirm the results of this study.

Supplementary data

To view the supplementary data that accompany this paper please visit the journal website at: www.futuremedicine.com/doi/suppl/10.2217/cer-2021-0068

Author contributions

All authors made substantial contributions to study conception and design, study recruitment and data acquisition and/or data analysis and interpretation (J Zhang, W Jiang and F Urdaneta); participated in drafting the manuscript (J Zhang) and/or revising it critically for important intellectual content (W Jiang, F Urdaneta); gave final approval of the final manuscript version submitted to be published (J Zhang, W Jiang, F Urdaneta); and agree to be accountable for all aspects of the work (J Zhang, W Jiang and F Urdaneta).

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J Zhang and W Jiang report employment with Medtronic; F Urdaneta is part of the Advisory Board for Vyaire Medical and a consultant for Medtronic and receives speaker honoraria for both. The authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed.

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Ethical conduct of research

The authors state that institutional review board approval was exempt because the data analyzed were de-identified and the study did not directly involve human subjects (45 CFR § 46.0001(b) (4)). The study was compliant with the principles outlined in the Declaration of Helsinki and the Health Insurance Portability and Accountability Act (HIPAA) for all human investigations.

Data sharing statement

The data for this study were used under license and may be available from Premier Inc.

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