Association of frailty with clinical and financial outcomes of esophagectomy hospitalizations in the United States☆

Mina G Park, MDa, Greg Haro, MDb, Russyan Mark Mabeza, BSa, Sara Sakowitz, MS, MPHa, Arjun Vermaa, Cory Lee, DOa, Catherine Williamson, BSa, Peyman Benharash, MDa,*

a Cardiovascular Outcomes Research Laboratories, Division of Cardiac Surgery, David Geffen School of Medicine at UCLA, Los Angeles, CA
b Department of Surgery, David Geffen School of Medicine at UCLA, Los Angeles, CA
USA

ABSTRACT

Background: Frailty, defined as impaired physiologic reserve and function, has been associated with inferior results after surgery. Using a coding-based tool, we examined the clinical and financial impact of frailty on outcomes following esophagectomy.

Methods: Adults undergoing elective esophagectomy were identified using the 2010–2018 Nationwide Readmissions Database. Using the binary Johns Hopkins Adjusted Clinical Groups frailty indicator, patients were classified as frail or nonfrail. Multivariable regression models were used to evaluate the association of frailty with in-hospital mortality, complications, hospitalization duration, costs, nonhome discharge, and unplanned 30-day readmission.

Results: Of 45,361 patients who underwent esophagectomy, 18.7% were considered frail. Most frail patients were found to have diagnoses of malnutrition (70%) or weight loss (15%) at the time of surgery. After adjustment, frailty was associated with increased risk of in-hospital mortality (adjusted odds ratio 1.67, 95% confidence interval 1.29–2.16) and overall complications (adjusted odds ratio 1.57, 95% confidence interval 1.44–1.71). Frailty conferred a 5.6-day increment in length of stay (95% confidence interval 4.94–6.45) and an additional $19,900 hospitalization cost (95% confidence interval $16,700–$23,100). Frail patients had increased odds of nonhome discharge (adjusted odds ratio 1.53, 95% confidence interval 1.35–1.75) as well as unplanned 30-day readmissions (adjusted odds ratio 1.17, 95% confidence interval 1.02–1.34).

Conclusion: Frailty, as detected by an administrative tool, is associated with worse clinical and financial outcomes following esophagectomy. The inclusion of standardized assessment of frailty in risk models may better inform patient selection and shared decision-making prior to operative intervention.

∗ Presented at the 17th Annual Academic Surgical Congress, February 1–3, 2022 in Orlando. The authors have no financial disclosures or conflicts of interest to report.

© 2022 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

INTRODUCTION

Despite significant advances in surgical technique and care, esophagectomy remains a high-risk operation with mortality rates up to 10% and postoperative complications occurring in nearly 40% of patients [1,2]. Careful risk assessment is crucial to patient selection and shared decision-making when choosing treatment options for esophageal disease. Although a multitude of traditional models incorporate patient age and comorbidities to estimate perioperative risk, the concept of frailty has emerged as an important predictor of adverse events [1–3]. Mounting evidence has linked frailty with increased mortality, complications, and health care expenditures following major operations including coronary artery bypass grafting, lung resection, and colectomy [4–6].

Although the exact definition of frailty remains equivocal, several physical and cognitive tests have been developed to characterize its presence. However, such frailty assessment methods have not been widely adopted in surgical practice because of their resource-intensive nature [7]. More recently, algorithms relying on administrative data have been employed to readily identify frailty. In fact, the American College of Surgeons National Surgical Quality Improvement Project (NSQIP) has incorporated several iterations of a coding-based frailty index into their risk models [8]. The addition of frailty has generally improved the discriminatory power of prediction models to better identify

https://doi.org/10.1016/j.sopen.2022.05.003
2589-8450 © 2022 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).
at-risk subject [8]. In an NSQIP study of 2095 esophagectomy patients, Hodari et al found a 30-fold increase in postoperative mortality in the presence of frailty [2].

With the known limitations of the Modified Frailty Index and the NSQIP database including selective center participation, the Johns Hopkins Adjusted Clinical Groups (ACG) frailty indicator has been introduced [9–11]. The ACG relies on diagnosis codes and can thus be widely applied to administrative data. Our group and several other investigators have previously reported on the significant impact of ACG classification on postoperative outcomes [4–6]. However, the utility of this frailty indicator in predicting risk of esophagectomy at the national level has not been evaluated.

The present national study characterized the association of the frailty, as measured by the ACG, with clinical outcomes and resource use following esophagectomy. We hypothesized frailty to be independently associated with increased risk of in-hospital mortality, perioperative complications, length of stay, hospitalization costs, and 30-day readmissions.

METHODS

The 2010–2018 Nationwide Readmissions Database (NRD) was queried to identify all elective, adult (≥18 years) hospitalizations for esophagectomy. The NRD is a national, all-payer database maintained by the Healthcare Cost and Utilization Project (HCUP) that accrues data from 27 states and provides accurate estimates for approximately 60% of all US hospitalizations. Previously reported International Classification of Diseases, Ninth and Tenth Edition, Clinical Modification (ICD-9/10-CM) diagnosis and procedure codes were used to identify hospitalizations for esophagectomy for benign and malignant indications [12]. Records with missing data for age, sex, in-hospital mortality, or hospitalization costs were excluded (4.1%).

Frailty was defined according to the Johns Hopkins Adjusted Clinical Groups diagnosis clusters, which included malnutrition, dementia, severe visual impairment, decubitus pressure ulcer, urinary incontinence, fecal incontinence, poverty, difficulty walking, and falls. Specific ICD diagnosis codes used to identify frailty qualifying diagnoses can be found in Supplementary Table 1. Patients were categorized as FRAIL if any 1 of the aforementioned diagnoses were present, and all others comprised the nonfrail cohort (nFRAL).

Patient and hospital characteristics of interest included age, sex, insurance payer, as well as hospital teaching status and bed size as defined in the HCUP data dictionary (NRD). The van Walraven modification of the Elixhauser Comorbidity Index, a previously validated composite score of 30 comorbidities, was used to quantify the burden of chronic conditions [13]. Patient comorbidities including history of chemoradiation and minimally invasive surgery increased among the FRAIL patients over 9 years (Fig 1).

FRAIL patients had a higher prevalence of esophageal cancer (53.5% vs 49.2%, P < .001), esophageal stricture (7.0% vs 4.2%, P < .001), and achalasia (4.0% vs 2.7%, P < .001) but lower rates of Barrett esophagus (6.1% vs 10.9%, P < .001) compared to others. Furthermore, FRAIL patients more frequently underwent open operations (81.7% vs 78.9%, P = .009) at large institutions (81.2% vs 77.1%, P = .006) and were insured by Medicare (51.5% vs 46.8%, P < .001).

RESULTS

Of an estimated 45,361 esophagectomy hospitalizations included for analysis, 8,490 (18.7%) comprised the FRAIL cohort. Malnutrition (70.0%) followed by weight loss (14.8%), dementia (6.9%), and pressure ulcers (6.4%) were among the most common frailty qualifying diagnoses (Table 1). Within the study period, the incidence of frailty increased from 16% in 2010 to 21% in 2018 (NPtrend < .001). The rates of perioperative chemoradiation and minimally invasive surgery increased among the FRAIL patients over 9 years (Fig 1).

Table 1

| ACG cluster | Representative diagnoses | Prevalence (%) |
|-------------|--------------------------|---------------|
| Malnutrition | Nutritional marasmus | 70.0 |
| Weight loss | Abnormal weight loss | 14.8 |
| Dementia | Presenile dementia | 6.9 |
| Severe vision impairment | Blindness in both eyes | 0.4 |
| Decubitus ulcer | Decubitus ulcer | 6.4 |
| Urinary incontinence | Incontinence without sensory awareness | 0.1 |
| Fecal incontinence | Fecal incontinence | 0.3 |
| Other functional disorders of bladder | Other functional disorders of bladder | 0.2 |
| Difficulty in walking | Abnormalities in gait and walking | 0.8 |
| Falls | Falls on and from stairs and steps | 0.1 |

Bivariate comparisons for categorical variables were performed using Pearson χ² test, whereas the adjusted Wald or β coefficients with 95% confidence intervals were used to optimize models, as appropriate. Regression outcomes are reported as adjusted odds ratios (AORs) and β coefficients with 95% confidence intervals (Cls). All statistical analyses were performed using Stata 16.1 (StataCorp, College Station, TX). This study was deemed exempt from full review by the University of California, Los Angeles Institutional Review Board.

Table 1 Prevalence of Johns Hopkins ACG frailty defining diagnosis clusters within the FRAIL cohort.
On unadjusted analysis, the rates of in-hospital mortality (6.1% vs 2.9%, \(P < .001\)) and perioperative complications such as respiratory (37.6% vs 23.3%, \(P < .001\)), infectious (19.5% vs 9.5%, \(P < .001\)), and gastrointestinal (14.1% vs 8.5%, \(P < .001\)) were higher in the FRAIL cohort when compared to their counterparts (Table 3). Furthermore, FRAIL patients experienced longer LOS (13 [9–23] vs 9 [7–14] days, \(P < .001\)) and incurred greater hospitalization costs ($53,800 [$35,700–$89,500] vs $39,400 [$26,800–$59,600], \(P < .001\)). Rates of nonhome discharge (23.9% vs 11.9%, \(P < .001\)) and 30-day unplanned readmission (16.3% vs 13.1%, \(P < .001\)) were also higher in the FRAIL.

After multivariable risk adjustment, frailty remained independently associated with increased odds of in-hospital mortality (AOR 1.59, 95% CI 1.29–1.95, Table 4). Frailty was further linked with a greater likelihood of developing respiratory, gastrointestinal, and infectious complications (Fig 2). Moreover, frailty conferred a 5.6-day incremental increase in LOS (95% CI 4.8–6.4) and +$19,900 in hospitalization costs (95% CI $16,700–$23,100). Frailty was associated with 53% and 17% increase in relative odds of nonhome discharge (95% CI 1.35–1.75) and 30-day unplanned readmission (95% CI 1.02–1.34, Fig 2), respectively.

Risk-adjusted estimates for in-hospital mortality by frailty status was calculated using the outputs of various multivariable logistic regressions. Frailty incurred a greater increment in adjusted mortality in the presence of several complications (Fig 3). Among all complication types, cardiac complication (30.3%, 95% CI 19.8–44.2 vs 18.7% 95% CI 12.2–27.3) was associated with the largest absolute difference in death between FRAIL and nFRAIL cohorts.

### Table 2
Demographics and clinical characteristics of patients undergoing esophagectomy stratified by frailty

|                     | FRAIL (n = 8,490) | nFRAIL (n = 36,872) | \(P\) value |
|---------------------|-------------------|--------------------|-------------|
| Age (y, SD)         | 64.5 ± 11.0       | 63.4 ± 10.9        | <.001       |
| Female (%)          | 23.2              | 23.9               | .427        |
| Elixhauser Comorbidity Index [IQR] | 4 [3–5] | 3 [2–4] | <.001 |
| Indication for surgery (%) | Malignancy | 80.4 | 78.8 | .101 |
|                     | History of chemotherapy | 28.2 | 28.9 | .51 |
| Comorbidities (%)   |                   |                    |             |
| Congestive heart failure | 6.3 | 4.7 | <.001 |
| Coronary artery disease | 12.2 | 15.3 | <.001 |
| Diabetes            | 15.7              | 18.5               | .001        |
| Hypothyroidism      | 6.7               | 8.4                | .003        |
| Chronic liver disease | 6.0 | 4.8 | .008 |
| Coagulopathy        | 8.5               | 5.4                | <.001       |
| Anemia              | 2.8               | 2.3                | <.001       |
| Insurance coverage (%) | Private | 35.2 | 42.7 | <.001 |
|                     | Medicare          | 51.5               | 46.8        |
|                     | Medicaid          | 8.8                | 6.9         |
| Other payer⁎        | 4.5               | 3.6                | .020        |
| Operative approach (%) | Open | 81.7 | 78.9 | .001 |
|                     | Laparoscopic      | 11.4               | 13.4        |
|                     | Robotic           | 6.9                | 7.7         |
| Hospital teaching status (%) | Nonmetropolitan | 1.8 | 1.0 | <.001 |
|                     | Metropolitan non teaching | 8.4 | 9.1 |       |
|                     | Metropolitan teaching | 89.8 | 89.9 |       |

Continuous variables are reported as mean with standard deviation or median with IQR. * Indicates a combined insurance status including self-pay, uninsured, and other.

### Table 3
Unadjusted outcomes following elective esophagectomy stratified by frailty.

|                     | FRAIL (n = 8,490) | nFRAIL (n = 36,872) | \(P\) value |
|---------------------|-------------------|--------------------|-------------|
| In-hospital mortality | 6.1 | 2.9 | <.001 |
| Complications       |                   |                    |             |
|                      | Cardiac           | 4.9                | 2.9         | <.001 |
|                      | Respiratory       | 37.6               | 23.3        | <.001 |
|                      | Gastroenterological | 14.1          | 8.5        | <.001 |
|                      | Infectious        | 19.9               | 9.5         | <.001 |
|                      | Cerebrovascular   | 0.6                | 0.3         | .032 |
|                      | Venous thromboembolic | 3.6 | 2.1 | <.001 |
|                      | Nonhome discharge | 23.9               | 11.9        | <.001 |
|                      | 30d nonelective readmission | 16.3 | 13.1 | <.001 |
|                      | LOS (d) [IQR]     | 13 [9–23]          | 9 [7–14]   | <.001 |
|                      | Costs ($1,000) [IQR] | 51.3 [34.3–87.8] | 37.9 [28.9–56.6] | <.001 |

All outcomes reported as percentage for dichotomous variables and median with IQR for continuous variables.
Frailty was linked with greater duration of hospitalization, costs, and in-hospital mortality and postoperative complications. Additionally, frailty was independently associated with increased risk of 30-day unplanned readmissions. Importantly, the present work demonstrates the feasibility of an administrative frailty instrument in refining risk prediction models for those undergoing elective esophagectomy.

Over the last decade, the concept of frailty has expanded beyond the normal aging process and accumulation of comorbidities [19]. Although more than 30 frailty tools have been reported, none have been adopted as standardized method of assessing frailty [7]. A simplified coding-based screening tool, like ACG frailty indicator, can be readily implemented into existing electronic medical record systems to enable timely screening, referrals, and appropriate specific evaluations of at-risk individuals. A myriad of previous works has studied the discriminatory power of ACG model of frailty in identifying frailty in the general elderly population as well as its association with poor perioperative outcomes across various surgical cohorts [4,6,20,21]. Because esophageal disease requires complex coordination of care across multiple disciplines, an administrative frailty screening tool may provide great benefit in streamlining referrals for ancillary services such as physical therapy, nutritional health, and wound care depending on the specific frailty qualifying diagnoses of the patient. For example, a simple automated alert system in the electronic medical records may provide a more realistic discussion of perioperative risk while allowing for implantation of targeted strategies for optimization. Unlike other administrative tools, ACG indicator does not include common comorbidities that overlap with traditional surgical risks but integrates specific domains of functional dependencies identifying specific areas for intervention. A broad application of ICD-based frailty indicator tool may allow for automated incorporation into risk models and facilitate choice of therapy as well as shared decision-making.

Using the Johns Hopkins ACG frailty indicator, we found nearly 20% of esophagectomy patients to be frail and >70% having a diagnosis of malnutrition. Hodari and colleagues observed similar rates of frailty (24%) using the modified Frailty Index in the National Surgical Quality Improvement Program database [2]. However, prealbumin, a marker of nutritional status, was not found to be associated with in-hospital mortality in their multivariable regression analysis [2]. Malnutrition and weight loss are well-known risk factors for esophagectomy patients and have independently been shown to portend poor outcomes across surgical specialties [22,23]. Although laboratory values are not available in the NRD, we noted frailty to be associated with 67% increase in the relative risk of mortality and complications particularly respiratory, infectious, and gastrointestinal. This finding is congruent with prior studies of patients undergoing esophagectomy and cardiac and lung operations [2,5,23]. Although frailty itself cannot be completely reversed, preoperative nutritional evaluation and optimization may improve outcomes for frail patients undergoing esophagectomy [22,23]. Furthermore, identifying the interaction between frailty, malnutrition, and high rates of respiratory and infectious complications in esophagectomy patients suggests early postoperative integration of ancillary services such as respiratory therapy and wound care. Cao and colleagues conducted a meta-analysis examining the effects of preoperative nutritional optimization for esophagectomy candidates and found a 50% reduction in infectious complications and a 2-day decrement in LOS [24]. Implementation of the ACG frailty tool in clinical settings may provide timely prompts to intervene and optimize esophagectomy candidates in a more standardized manner.

Our work highlights the significant burden of frailty on expenditures following elective esophagectomy. Following adjustment for other risk factors, patients classified as frail experienced an additional 4 days in hospitalization, costs, and risk of 30-day unplanned readmissions. Importantly, the present work demonstrates the feasibility of an administrative frailty instrument in refining risk prediction models for those undergoing elective esophagectomy.

**Table 4** Risk-adjusted multivariable regression model for in-hospital mortality following elective esophagectomy.

| Patient demographics | AOR (95% CI) | P value |
|----------------------|-------------|---------|
| Year (per year)      | 0.96 (0.92–0.99) | .021 |
| Age (per year)       | 1.04 (1.03–1.06) | <.001 |
| Female               | 0.98 (0.77–1.24) | .85 |
| Frailty              | 1.59 (1.29–1.95) | <.001 |
| Elixhauser Comorbidity Index | 1.12 (1.05–1.19) | <.001 |
| Indication           |             |         |
| Malignant            | 1.27 (0.92–1.75) | .15 |
| Benign               | 0.61 (0.50–0.75) | <.001 |
| History of chemotherapy | 0.52 (0.41–0.66) | <.001 |
| Comorbidities        |             |         |
| Congestive heart failure | 2.07 (1.54–2.77) | <.001 |
| Coronary artery disease | 0.65 (0.49–0.86) | .002 |
| Diabetes             | 0.72 (0.54–0.96) | .023 |
| Hypothyroidism       | 0.31 (0.20–0.49) | <.001 |
| Liver disease        | 2.39 (1.76–3.23) | <.001 |
| Coagulopathy         | 2.02 (1.52–2.68) | <.001 |
| Anemia               | 0.54 (0.21–1.38) | .20 |
| Payer type           |             |         |
| Medicare             | 1.44 (1.10–1.88) | .006 |
| Medicaid             | 1.57 (1.04–2.36) | .030 |
| Other†               | 2.21 (1.37–3.58) | .00 |
| Operative characteristics |             |         |
| Open                 |             |         |
| Laparoscopic         | 0.56 (0.41–0.75) | <.001 |
| Robotic              | 0.58 (0.42–0.82) | .002 |
| Hospital teaching status |             |         |
| Rural                |             |         |
| Urban non-teaching    | 1.08 (0.45–2.6) | .87 |
| Urban teaching       | 0.74 (0.32–1.74) | .50 |

Ref. reference. † Indicates a combined insurance status including self-pay, uninsured, and other.

**DISCUSSION**

In the present nationally representative study, we examined the association of frailty, as measured by a coding-based method, with postoperative outcomes following elective esophagectomy and made several important observations. Using the proprietary ACG frailty tool, nearly 1 in 5 patients undergoing esophagectomy was classified as frail. We observed frailty to be independently associated with increased in-hospital mortality and postoperative complications. Additionally, frailty was linked with greater duration of hospitalization, costs, and risk of 30-day unplanned readmissions. Importantly, the present work demonstrates the feasibility of an administrative frailty instrument in refining risk prediction models for those undergoing elective esophagectomy.

Over the last decade, the concept of frailty has expanded beyond the normal aging process and accumulation of comorbidities [19]. Although more than 30 frailty tools have been reported, none have been adopted as standardized method of assessing frailty [7]. A simplified coding-based screening tool, like ACG frailty indicator, can be readily implemented into existing electronic medical record systems to enable timely screening, referrals, and appropriate specific evaluations of at-risk individuals. A myriad of previous works has studied the discriminatory power of ACG model of frailty in identifying frailty in the general elderly population as well as its association with poor perioperative outcomes across various surgical cohorts [4,6,20,21]. Because esophageal disease requires complex coordination of care across multiple disciplines, an administrative frailty screening tool may provide great benefit in streamlining referrals for ancillary services such as physical therapy, nutritional health, and wound care depending on the specific frailty qualifying diagnoses of the patient. For example, a simple automated alert system in the electronic medical records may provide a more realistic discussion of perioperative risk while allowing for implantation of targeted strategies for optimization. Unlike other administrative tools, ACG indicator does not include common comorbidities that overlap with traditional surgical risks but integrates specific domains of functional dependencies identifying specific areas for intervention. A broad application of ICD-based frailty indicator tool may allow for automated incorporation into risk models and facilitate choice of therapy as well as shared decision-making.

Using the Johns Hopkins ACG frailty indicator, we found nearly 20% of esophagectomy patients to be frail and >70% having a diagnosis of malnutrition. Hodari and colleagues observed similar rates of frailty (24%) using the modified Frailty Index in the National Surgical Quality Improvement Program database [2]. However, prealbumin, a marker of nutritional status, was not found to be associated with in-hospital mortality in their multivariable regression analysis [2]. Malnutrition and weight loss are well-known risk factors for esophagectomy patients and have independently been shown to portend poor outcomes across surgical specialties [22,23]. Although laboratory values are not available in the NRD, we noted frailty to be associated with 67% increase in the relative risk of mortality and complications particularly respiratory, infectious, and gastrointestinal. This finding is congruent with prior studies of patients undergoing esophagectomy and cardiac and lung operations [2,5,23]. Although frailty itself cannot be completely reversed, preoperative nutritional evaluation and optimization may improve outcomes for frail patients undergoing esophagectomy [22,23]. Furthermore, identifying the interaction between frailty, malnutrition, and high rates of respiratory and infectious complications in esophagectomy patients suggests early postoperative integration of ancillary services such as respiratory therapy and wound care. Cao and colleagues conducted a meta-analysis examining the effects of preoperative nutritional optimization for esophagectomy candidates and found a 50% reduction in infectious complications and a 2-day decrement in LOS [24]. Implementation of the ACG frailty tool in clinical settings may provide timely prompts to intervene and optimize esophagectomy candidates in a more standardized manner.

Our work highlights the significant burden of frailty on expenditures following elective esophagectomy. Following adjustment for other risk factors, patients classified as frail experienced an additional 4 days in length of stay and incurred an excess of nearly $15,000 in index hospitalization costs. These findings may be attributable to the presence of postoperative complications as well as intensity of care, a variable that could not be measured in NRD. Our results corroborate prior work noting a similar association in coronary artery bypass surgery and lung resections [4,5]. Among those surviving index hospitalizations, 24% of frail patients required postoperative rehabilitation facilities upon discharge compared to 12% in the nonfrail cohort. Moreover, frail patients were...
17% more likely to be readmitted within 30 days of discharge. Taken together, our findings point to major clinical and financial implications of frailty in surgical practice, which may be mitigated with early detection and optimization. Patient selection and shared decision-making of different treatment modalities, such as definitive chemoradiation, may be better guided with a calibrated prediction of clinical and financial risk.

The present study has several important limitations. As a clinical indicator, the ACG frailty Index may be influenced by local coding practices. Furthermore, the database does not account for outpatient care, and our analysis is limited to index hospitalizations and readmissions. Granular clinical data, such as tumor location and staging, method of esophagectomy, and the use of neoadjuvant chemotherapy or radiation, were not captured. Despite these limitations, we used the largest available all-payer readmissions database and robust statistical methods to reduce the risk of bias.

In conclusion, we found frailty, as measured by an administrative tool, to be independently associated with increased in-hospital mortality, postoperative complications, and resource utilization among patients undergoing esophagectomy. Implementation of the ACG frailty indicator into routine clinical evaluation may aid risk stratification, shared decision-making, and optimization of esophagectomy candidates.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sopen.2022.05.003.

Author Contribution
All authors have contributed to the manuscript.

Conflict of Interests
The authors have no related conflicts of interest to declare.

Funding Source
None.

Ethics Approval
This study was deemed exempt from full review by Internal Review Board at University of California Los Angeles.

References
[1] Gray KD, Nobel TB, Hsu M, et al. Improved preoperative risk-assessment tools are needed to guide informed decision-making before esophagectomy [Published online 2020]. https://doi.org/10.1097/SLA.0000000000004715.
[2] Hodari A, Hammoud ZT, Borgi JF, Tsiouris A, Rubinfeld IS. Assessment of morbidity and mortality after esophagectomy using a modified frailty index. Ann Thorac Surg. 2013;96(4):1240–5. https://doi.org/10.1016/j.athoracsur.2013.05.051.
[3] Tang A, Ahmad U, Raja S, et al. Looking beyond the eyeball test: a novel vitality index to predict recovery after esophagectomy. J Thorac Cardiovasc Surg. 2021;161(3):822–32.e6. https://doi.org/10.1016/j.jtcvs.2020.10.122.
[4] Dobaria V, Hadaya J, Sanaiha Y, Aguayo E, Sareh S, Benharash P. The Pragmatic impact of frailty on outcomes of coronary artery bypass grafting. 2021 Jul;112(1):108–15. https://doi.org/10.1016/j.athoracsur.2020.08.028.
[5] Karunungan K, Hadaya J, Tran Z, et al. Frailty is independently associated with worse outcomes after elective anatomic lung resection. 2021 Nov;112(5):1639–46. https://doi.org/10.1016/j.athoracsur.2020.11.004.
[6] Hadaya J, Sanaiha Y, Julliard C, Benharash P. Impact of frailty on clinical outcomes and resource use following emergency general surgery in the United States. PLoS One. 2021;16(July). https://doi.org/10.1371/journal.pone.0255122.
[7] Kim DH. Measuring frailty in health care databases for clinical care and research. Ann Geriatr Med Res. 2020;24(2):62–74. https://doi.org/10.4235/agmr.20.00002.
[8] Subramanium S, Aalberg JJ, Soriani RM, Divino CM. New 5-factor modified frailty index using American College of Surgeons NSQIP data. J Am Coll Surg. 2018;226(2):173–181.e8. https://doi.org/10.1016/j.jamcollsurg.2017.11.005.
[9] Gani F, Canner JK, Pawlik TM. Use of the modified frailty index in the American College of Surgeons National Surgical Improvement Program Database. JAMA Surg. 2017;152(2):205. https://doi.org/10.1001/jamasurg.2016.3479.
[10] Sheils CR, Dahlke AR, Yang A, Bilimoria K. NSQIP hospitals unique? A description of hospitals participating in ACS NSQIP. Present Acad Surg Congr. 2016. [Published online February 3, 2016]. https://www.asc-abstracts.org/abs2016/51-09-are-nsqip-hospitals-unique-a-description-of-hospitals-participating-in-acs-nsqip.
[11] The Johns Hopkins adjusted clinical group technical reference guide, version 9.0; 2009.
[12] Gandjian M, Williamson C, Sanaiha Y, et al. Continued relevance of minimum volume standards for elective esophagectomy: a national perspective. Annals of thoracic surgery. Elsevier Inc.; 2021https://doi.org/10.1016/j.athoracsur.2021.07.061.
[13] Van Wairavan C, Austin PC, Jennings A, Quan H, Forster AJ. A modiﬁcation of the Elixhauser comorbidity measures into a point system for hospital death using administrative data. www.how-medicalcare.com; 2009.
[14] Bolourani S, Tayebi MA, Diao L, et al. Using machine learning to predict early readmission following esophagectomy. J Thorac Cardiovasc Surg. 2021;161(6):1926–31.e3. https://doi.org/10.1016/j.jtcvs.2020.11.059.
[15] Low DE, Kuppusamy MK, Alderson D, et al. Benchmarking complications associated with esophagectomy. Ann Surg. 2019;269(2):291–8. https://doi.org/10.1097/SLA.0000000000002611.
[16] NRD overview. https://www.hcup-us.ahrq.gov/nrdoverview.jsp.

Fig 3. Adjusted absolute risk of in-hospital mortality associated with various complications in frail and nonfrail patients.
[17] Cuzick J. A Wilcoxon-type test for trend. Stat Med. 1985;4(1):87–90. https://doi.org/10.1002/sim.4780040112.

[18] Zou H, Hastie T. Regularization and variable selection via the elastic net. J R Stat Soc Ser B (Statistical Methodol). 2005;67(2):301–20. https://doi.org/10.1111/j.1467-9868.2005.00503.x.

[19] Hoogendijk EO, Afilalo J, Ensrud KE, Onder G, Fried LP. Frailty: implications for clinical practice and public health. Lancet. 2019;394(10206):1365–75. https://doi.org/10.1016/S0140-6736(19)31786-6.

[20] Sternberg SA, Bentur N, Abrams C, et al. Identifying frail older people using predictive modeling. Am J Manag Care. 2012;18(10):e392–7.

[21] Nieman CL, Pitman KT, Tufaro AP, Eisele DW, Frick KD. Courin CG. The effect of frailty on short-term outcomes after head and neck cancer surgery. Laryngoscope. 2018;128(1):102–10. https://doi.org/10.1002/lary.26735.

[22] Emami S, Rudasill S, Bellamkonda N, et al. Impact of malnutrition on outcomes following transcatheter aortic valve implantation (from a national cohort). Am J Cardiol. 2020;125(7):1096–101. https://doi.org/10.1016/j.amjcard.2019.12.038.

[23] Rudasill S, Gittings DJ, Elkassabany NM, Liu J, Nelson CL, Kamath AF. Preoperative risk factor score predicts malnutrition in total joint arthroplasty patients. J Surg Orthop Adv. 2019;28(2):97–103.

[24] Cao Y, Han D, Zhou X, Han Y, Zhang Y, Li H. Effects of preoperative nutrition on postoperative outcomes in esophageal cancer: a systematic review and meta-analysis. Dis Esophagus. 2022 Mar 12;35(3). https://doi.org/10.1093/dote/doab028. [Published online May 10, 2021]. doab028.