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Featured Article

Measuring malnutrition and its impact on pediatric surgery outcomes: A NSQIP-P analysis☆,☆☆,☆☆☆

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Background: There is a limited understanding of the impact of pediatric malnutrition indicators on post-operative outcomes.
Materials and methods: All pediatric surgical patients captured in the ACS NSQIP-Pediatric database from 2016 to 2018 were included. Multivariable logistic regression was used to estimate odds of 30-day post-operative infection by malnutrition definition (stunted, wasted, requiring nutritional support, pre-operative hypoalbuminemia).
Results: Among pediatric surgery patients (n = 282,056), 19% of patients met one definition of malnutrition, 6% met two, 1% met 3, and <0.1% met all 4. After adjustment, requiring nutritional support (OR 1.47, 95% CI 1.36–1.60), stunting (OR 1.17, 95% CI 1.10–1.25), and hypoalbuminemia (OR 1.17 95% CI 1.04–1.32) were associated with increased odds of post-operative infection while wasting was not. Requiring nutritional support was associated in an increase of 10.17 days (95% CI 9.89–10.44) in time from admission to surgery.
Conclusions: The metric used to define malnutrition changed the association with post-operative outcomes. Nutritional supplementation, stunting, and hypoalbuminemia were associated with poorer postoperative outcomes. These findings have implications for pre-operative patient level counseling, accurate risk stratification, surgical planning, and patient optimization in pediatric surgery.
Level of Evidence: III.

The National Surgical Quality Improvement Program-Pediatric (NSQIP-P) is a multi-specialty program which tracks pre-operative patient and clinical factors associated with specified procedures as well as their 30-day outcomes [1]. The purpose of NSQIP-P is to provide risk adjusted interhospital comparisons, to identify areas where surgical quality can be improved. Additionally, this unique database was developed to allow for identification of modifiable risk factors in larger data sets for the improvement of pediatric surgical quality generally. Previous studies using NSQIP-P have identified pre-operative malnutrition as a potentially modifiable risk factor for the prevention of surgical complications [2–5]. However, these previous studies have examined varying classifications of malnutrition and varying surgical populations, and the definition of malnutrition with the largest association with overall post-operative infectious complications has not been identified.

Malnutrition is a highly prevalent condition in hospitalized pediatric patients, and has been shown to be associated with increased morbidity in pediatric surgery [4,6,7]. **Previous studies using the NSQIP-P database have included the need for nutritional support variable included in NSQIP-P and anthropomorphic measures of malnutrition** [5]. The World Health Organization (WHO) uses standardized anthropometric measures (z-scores) to categorize pediatric malnutrition into underweight, stunting (indicating low height for age), wasting (indicating low weight for height), and severe protein calorie malnutrition [8]. For stunting and wasting, Z-scores more than two standard deviations below the average indicate severe malnutrition [9,10]. **However, severe protein calorie malnutrition requires evidence of changes to body**

Abbreviations: NSQIP-P, National Surgical Quality Improvement Program-Pediatric; OR, odds ratio; CI, confidence interval; SSI, surgical site infection; UTI, urinary tract infection; CLABSI, central line-associated bloodstream infection; CIE, change in estimate; LOS, length of stay.

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composition and cannot be extrapolated solely from anthropomorphic measures.

Hypoalbuminemia has previously been used as a surrogate for decreased serum protein production in severe malnutrition, and has been used for pre-operative screening for malnutrition and risk stratification in adults [11,12]. Hypoalbuminemia has also been hypothesized to be a marker of malnutrition in pediatric populations; however, the data in this population are less clear. As such, albumin levels are usually used in conjunction with anthropometrically derived markers of malnutrition like stunting and wasting for pre-operative risk assessment [13–15]. However, no single factor or combination of factors has been identified to accurately and consistently predict pre-operative risk for surgery, and results have varied depending on the metric used [2–7,16–20]. For example, among children who had abdominal or thoracic surgery, being stunted was associated with increased risk of 30-day post-operative complications, but wasting was not [5]. Additionally, in a study of pediatric patients with heart disease at high surgical risk, low pre-operative albumin was associated with increased length of stay after surgery [19]. A recent systematic review found a lack of evidence for the relationship between pre-operative nutritional status and post-operative clinical outcomes due in part to varying modes of pre-operative nutritional assessment [7].

To improve pediatric surgical outcomes by optimizing modifiable risk factors pre-operatively, a better understanding of the relationships between various clinical definitions of malnutrition and their impact on surgical outcomes is needed. Thus, the objective of this study was to examine the relationship between four **previously published measures of nutritional status within NSQIP-P**: stunting, wasting, requiring nutritional support (enteral or parenteral), and pre-operative hypoalbuminemia, and their predictive ability for post-operative infectious outcomes in pediatric patients.

1. Methods

1.1. Data source and study population

Data were obtained from the 2016–2018 ACS NSQIP-P, a national database of hospitals designed to assess risk-adjusted pediatric surgery patient outcomes. Data are abstracted by trained reviewers and include patient demographics, clinical characteristics, and up to 30-day post-operative outcomes. The design of this database has been described previously [1,21]. All pediatric surgical hospitalizations included in the 2016–2018 NSQIP-P database were eligible for inclusion. Patients were excluded if they had missing or impossible height or weight values (n = 45,425 and n = 7823, respectively). We assessed impossible height and weight values separately for patients <2 and ≥2 years old. Impossible value cut points were determined to be the top or bottom one percentile of weight, height, or body mass index (BMI) within the respective age group. For example, among children ≥2 years old, those with a recorded height <16 in. or >8 ft were excluded.

1.2. Malnutrition metrics

Four previously published definitions of malnutrition were considered as potential predictors for poor post-operative outcomes: stunting, wasting, requiring nutritional support, and hypoalbuminemia [13,22–24] .Stunting was defined as being more than 2 standard deviations below the average height for age, and wasting was defined as being 2 standard deviations below the average weight for recumbent length for children <2 years old, and BMI for age for children ≥2 years old. Distributions for these metrics were derived by the Centers for Disease Control and Prevention (CDC). All distributions were gender-stratified and reported in half-month (height for age) or one-month (weight for length and BMI for age) increments. Requiring nutritional support is captured in NSQIP-P and defined as receiving enteral feedings or intravenous total parenteral nutrition at the time of the surgical procedure. Pre-operative albumin levels are also captured and were available for children who were tested. Children who had albumin levels <3 g per deciliter (g/dL) were categorized as having hypoalbuminemia. Children with albumin levels ≥3.0 g per deciliter (g/dL) were categorized as having albumin levels within normal range. For analyses involving hypoalbuminemia as a predictor we conducted a complete case analysis excluding those patients with missing values. These definitions have been used previously [13,22–24].

1.3. Thirty-day post-operative outcomes

The primary outcome of interest was 30-day incidence of infection. Types of infections included surgical site infection (SSI) which included organ space, superficial and deep. Non-SSI post-operative outcomes included pneumonia, urinary tract infection (UTI), central line-associated blood stream infection (CLABSI), and *Clostridium difficile* infection. Secondary outcomes included time from admission to surgery and length of stay after surgery. Length of stay after surgery was calculated by subtracting number of days from admission to surgery from total length of stay.

1.4. Statistical analyses

Baseline demographics and clinical characteristics were compared across age at admission, which was categorized into neonate (<30 days), infant (1 months-2 years), child (3–12 years), adolescent (13–17 years). Surgery type was determined by the primary CPT code on the patient record. CPT code lists for gastrointestinal and thoracic surgery were provided by NSQIP-P. Other surgery types (neurosurgery orthopedic, otolaryngology, plastic surgery, urology), were determined by examining the distribution of provider specialty for each CPT code. If >50% of procedures were performed by a given specialty (e.g. neurosurgery), they were classified as such. Due to the prevalence of appendectomy in the pediatric population (CPT codes 44,950, 44,960, 44,970, 44,979, 44,900), they were flagged separately.

Multivariable logistic and linear regression was used to estimate the association between each of the four definitions of malnutrition and odds of infection, time to surgery and length of stay after surgery. Models were adjusted for race, ethnicity, comorbidities, surgery type, age group, gender, operation time (treated as a restricted quadratic spline), laparoscopic surgery, preoperative steroid use, wound classification, elective admission, and ASA type. Comorbidities were reported by NSQIP-P and included respiratory disease, cardiac risk factors, gastrointestinal disease, central nervous system disorders, hematologic disease, diabetes, immunosuppressed disorders, kidney disease and congenital malformation.

Several sensitivity analyses were also performed. First, multivariable logistic and linear regression were used to estimate the relationship between number of malnutrition definitions met (range 0 [met no definitions] to ≥3 [met 3 or 4 definitions]) and the outcomes of interest (infection, time to surgery, length of stay after surgery). Given the high prevalence of missing pre-operative albumin labs, a secondary analysis evaluating factors associated with presence of an albumin level was also conducted (performed vs. not performed). Bivariable binomial regression was used to estimate the prevalence and prevalence differences (PD) by malnutrition status, age group, case type, surgery type, and comorbidity.

We also conducted an imputed analysis setting all missing albumin lab values to normal to ascertain the lower bound of the association between hypoalbuminemia and postoperative outcomes. Multivariable logistic and linear regression was used to estimate the relationship between hypoalbuminemia and infection risk, time to surgery, and length of stay after surgery among those who had a blood test.

All statistical analyses were carried out using SAS version 9.4 (SAS Inc., Cary, NC). Fig. 1 was created using R version 4.0.0 and the UpSetR package [25]. This study was exempted from review by the Institutional

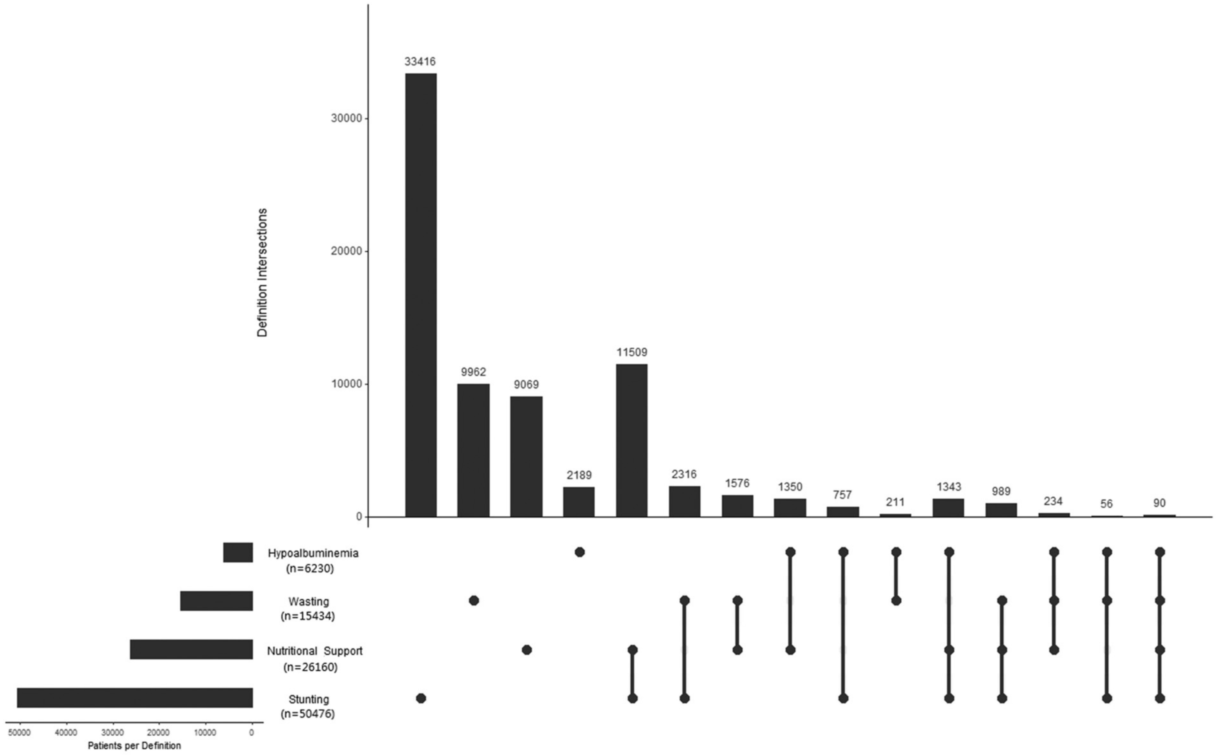

Fig. 1. The number of patients who meet criteria for each of the definitions of malnutrition identified within National Surgical Quality Improvement Project-Pediatric (NSQIP-P). Among patients classified as malnourished by at least one definition (n=75,067), 73% met only one definition of malnutrition, 24% (n=17,719) met two definitions of malnutrition, 3% (n= 2,2622) met 3 definitions of malnutrition, and <1% (n=90) met all 4 definitions of malnutrition. Only the combination of Nutritional Support and Stunting was relatively common (n=11,509, 15% of malnourished patients).

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2. Results

2.1. Cohort characteristics

Overall 282,046 hospitalizations were included; 4% of surgeries were in neonates, 24% were in infants, 43% were in children, and 30% in adolescents. Among all hospitalizations, 19% (n = 54,636) of patients met one definition of malnutrition, 6% (17,719) met two definitions, 1% (n = 2622) met 3 definitions, and < 0.1% (n = 90) met all 4 definitions of malnutrition. There was only modest overlap across definitions as 73% of malnourished patients were only classified using a single definition, Fig. 1. The prevalence of each definition varied across age group, Table 1. Children (3–12 years old) were most likely to require nutritional support (67%), neonates were most likely to be classified as wasted (13%) and hypoalbuminemic (25%), while infants were most likely to be identified as stunted (32%). The most prevalent combination of malnutrition definitions met was requiring nutritional support and stunting (13%). Patient and surgery characteristics are reported in Table 1 stratified by age group.

2.2. Malnutrition and infection risk

There were 8824 infections (5872 SSIs, 3249 other infections) within 30-days of surgery, Appendix 1. Post-operative infection prevalence was highest among neonates at 5%. After adjusting for confounding variables, requiring nutritional support (OR 1.47; 95% CI 1.36–1.60), stunting (OR 1.17; 95% CI 1.10–1.25), and hypoalbuminemia (OR 1.13 95% CI 1.00–1.28) were all associated with increased odds of any infection; no difference was seen in patients who were wasted (OR 1.00; 95% CI 0.91–1.10). The increased risk for patients requiring nutritional support and those with hypoalbuminemia were relatively consistent across all infection types, Table 2. Stunting appeared to only increase the odds of certain infections; for example, stunting was not associated with *C. difficile* (OR 0.97; 95% CI 0.75–1.25) or CLABSI (OR 0.84; 95% CI 0.58–1.20), but was associated with increased odds of pneumonia (OR 1.23; 95% CI 1.05–1.43). Meeting multiple definitions for malnutrition generally appeared to increase a patient's risk for post-operative complications; however, confidence intervals overlapped substantially for several outcomes, Appendix 2.

In age-stratified analyses, requiring nutritional support was associated with increased odds of any infection across all age groups, Table 3. Hypoalbuminemia was associated with increased odds of any infection for children (OR 1.27; 95% CI 1.01–1.59) but not for neonates (OR 0.94; 95% CI 0.66–1.33). Hypoalbuminemia appeared to be associated with adolescents, but estimates were imprecise and not statistically significant OR 1.26; 95% CI 0.96–1.64). Stunting was only associated with infection in children (OR 1.16; 95% CI 1.05–1.29) and adolescents (OR 1.27; 95% CI 1.11–1.45) while wasting did not predict infection in any age group.

2.3. Malnutrition, time to surgery, and length of stay after surgery

Median time to surgery was 2 days (IQR 0–25) for patients requiring nutritional support, 0 days (IQR 0–1) for patients who were wasted or stunted, 5 days (IQR 1–21) for patients with hypoalbuminemia and 0 days (IQR 0–0) for patients who met no malnutrition indicators. Median length of stay after surgery was 4 days (IQR 2–11) for patients requiring nutritional support, 2 days (IQR 1–4) for patients who were wasted or stunted, 9 days (IQR 4–19) for patients with hypoalbuminemia and 1 day (IQR 0–2) for patients who met no malnutrition indicators, Appendix 1. After adjustment, requiring nutritional support was associated with a 10.17 day (95% CI 9.89–10.44) average increase in time from admission to surgery and a 2.63 (95% 2.55–2.72) day average increase in length

Table 1
Demographic characteristics of the study population NSQIP-P 2016–2018, stratified by age.

	Neonate 9911 (4%)	Infant 66,428 (24%)	Child 121,123 (43%)	Adolescent 84,584 (30%)
Malnutrition, n (%)				
Requires nutritional support[a]	3190 (12)	12,798 (19)	7326 (6)	2846 (3)
Wasted[b]	1267 (13)	4927 (7)	5330 (4)	3910 (5)
Stunted[c]	1534 (16)	21,028 (32)	17,100 (14)	10,814 (13)
Hypoalbuminemia[d]	1536 (39)	2147 (16)	1413 (6)	1134 (5)
Missing albumin lab	5936 (60)	53,267 (80)	98,906 (82)	60,723 (72)
Male, n (%)	6288 (63)	41,868 (63)	66,886 (55)	41,610 (49)
Prematurity, n (%)	1637 (17)	16,499 (25)	14,665 (12)	6325 (7)
Missing birth status	112 (1)	2584 (4)	20,238 (17)	19,597 (23)
Race, n (%)				
White	6438 (80)	44,169 (78)	84,473 (81)	61,275 (83)
Black or African American	1221 (15)	9535 (17)	14,505 (14)	10,155 (14)
Asian	304 (4)	2236 (4)	4725 (5)	2197 (3)
American Indian or Alaska Native	53 (1)	349 (1)	587 (1)	356 (<1)
Native Hawaiian or Other Pacific Islander	45 (1)	392 (1)	674 (1)	332 (<1)
Hispanic, n (%)	1746 (20)	10,501 (17)	22,221 (20)	14,154 (18)
Comorbidities, n (%)				
Respiratory				
Ventilator dependence	1780 (18)	3514 (5)	1961 (2)	1141 (1)
Oxygen support	1687 (17)	5631 (9)	2032 (2)	871 (1)
Tracheostomy	17 (<1)	1246 (1.9)	2027 (2)	562 (1)
Airway abnormalities	1256 (13)	8566 (13)	7873 (7)	3411 (4)
Chronic lung disease	183 (2)	6561 (10)	4665 (4)	1712 (2)
Asthma	23 (<1)	1560 (2)	9381 (8)	5855 (7)
Cardiac	3466 (35)	16,264 (25)	9663 (8)	4417 (5)
Gastrointestinal	5252 (53)	20,197 (30)	13,821 (11)	9324 (11)
CNS				
Seizure disorder	211 (2)	3124 (5)	9431 (8)	5879 (7)
Cerebral palsy	12 (<1)	574 (1)	6743 (6)	4261 (5)
Neuromuscular disorder	277 (3)	3110 (5)	8370 (7)	5384 (6)
Structural abnormality	1718 (17)	10,777 (16)	16,848 (14)	8499 (10)
Hematologic	570 (6)	4394 (7)	4052 (3)	3089 (4)
Diabetes	<11 (<1)	152 (<1)	145 (<1)	56 (<1)
Immunosuppressed	<11(<1)	40 (<1)	111 (<1)	60 (<1)
Kidney disease	162 (2)	818 (1)	859 (1)	325 (<1)
Congenital malformation	5793 (59)	30,400 (46)	33,533 (28)	14,749 (17)
Pre-operative steroids, n (%)	410 (4)	2274 (3)	2682 (2)	2157 (3)
Pre-operative sepsis, n (%)				
SIRS	173 (2)	766 (1)	7125 (6)	6966 (8)
Sepsis	94 (1)	865 (1)	6071 (5)	3344 (4)
Septic shock	47 (1)	68 (<1)	94 (<1)	86 (<1)
Surgery type, n (%)				
Gastrointestinal	4084 (41)	15,209 (23)	10,874 (9)	11,511 (14)
Thoracic	110 (1)	1147 (2)	1315 (1)	3205 (4)
Neurosurgery	1382 (14)	9100 (14)	13,047 (11)	7345 (9)
Orthopedic	74 (1)	2467 (4)	24,764 (20)	21,456 (25)
ENT	526 (5)	9206 (14)	19,882 (16)	8233 (10)
Plastics	93 (1)	8387 (13)	6477 (5)	3366 (4)
Urology	257 (3)	11,196 (17)	12,355 (10)	3373 (4)
Appendectomy	39 (<1)	194 (<1)	19,762 (16)	15,684 (19)
Other	3346 (34)	9522 (14)	12,647 (10)	10,411 (12)
ASA score, n (%)				
None (1)	722 (7)	14,623 (22)	38,624 (32)	23,842 (28)
Mild (2)	2818 (29)	26,421 (40)	52,555 (43)	42,100 (50)
Severe (3)	4504 (46)	21,163 (32)	27,692 (23)	17,354 (21)
Life threatening (4–5)	1804 (18)	4113 (6)	2086 (2)	1119 (1)
Wound classification, n (%)				
Clean	4024 (41)	25,518 (38)	55,500 (46)	42,710 (51)
Clean-contaminated	4862 (49)	37,746 (57)	44,308 (37)	25,297 (30)
Contaminated	643 (7)	1557 (2)	12,345 (10)	11,451 (14)
Dirty	382 (4)	1607 (22)	8970 (7)	5126 (6)
Elective admission, n (%)	4785 (48)	57,559 (87)	88,735 (73)	62,960 (74)
Laparoscopic/MIS, n (%)	2829 (29)	18,473 (28)	37,930 (31)	32,634 (39)
Surgery time in minutes, med (IQR)	66 (33–121)	75 (37–132)	59 (32–121)	80 (44–162)

of stay after surgery, Table 2. Hypoalbuminemia was associated with a 1.07 (95% CI: 0.39–1.74) day average increase in time to surgery from admission and a 3.32 (95% CI 3.09–3.54) day average increase in length of stay after surgery. Stunting was associated with increased time to surgery (CIE 3.09; 95% CI 2.91–3.27) but had minimal impact on length of stay after surgery (CIE 0.23; 95% CI 0.17–0.28), Wasting was not associated with increased time to surgery or length of stay after surgery.

2.4. Pre-operative albumin tests

Pre-operative albumin labs were not available in 60% of neonates, 80% of infants, 82% of children, and 72% of adolescents, Table 1. The probability of having a blood test performed (irrespective of the result) was associated with several patient and hospitalization characteristics, Table 4. Patients receiving nutritional support were 25% more likely to have an albumin level than those not receiving nutritional support. Patients classified as wasted or stunted, compared to normal weight for height and height for age, respectively, were both 7% more likely to be tested. Other factors associated with greater likelihood of being tested were children undergoing emergency or urgent surgery (25% more likely, compared to elective), gastrointestinal or thoracic surgery (28% and 13% more likely, compared to orthopedic surgery), ventilator dependent (30% more likely), those requiring oxygen support (30% more likely), chronic lung disease (13% more likely). Patients with cardiac risk factors (11% more likely), gastrointestinal disease (13% more likely), and hematologic conditions (33% more likely) also had a higher prevalence of having an albumin value compared to patients without those conditions.

In sensitivity analyses imputing all missing albumin values to normal levels, hypoalbuminemia remained associated with increased odds of surgical site infection (OR 1.18; 95% CI 1.02–1.36). Further, hypoalbuminemia was also associated with *C. difficile* infection (OR 1.91; 95% CI 1.32–2.75) and occurrence of any infection in children (OR 1.27; 95% CI 1.01–1.59), Table 2. Time to surgery (CIE 3.06; 95% CI 2.60–3.51) and length of stay after surgery (CIE 4.52; 95% CI 4.37–4.66) were also increased among patients with hypoalbuminemia.

3. Discussion

We evaluated 280,000 hospitalizations of pediatric surgery patients between 2016 and 2018 in the NSQIP-P database and demonstrated that stunting, hypoalbuminemia, and need for nutritional support were consistent risk factors for SSIs and other infectious complications. Additionally, while stunting, hypoalbuminemia and need for nutritional support had similar odds of developing SSIs, need for nutritional support was associated with the highest odds of any infectious complication. Need for nutritional support was also associated with an increased pre-operative length of stay of 10.2 days and a post-operative length of stay of 2.6 days, while stunting and hypoalbuminemia were associated with more modest increases in preoperative length of stay. However, hypoalbuminemia was associated with a post-operative length of stay of 3.3 days. These findings are unique and the first to establish that the need for supplemental nutrition appears to be most consistent predictor of poor post-operative outcomes in pediatric surgery.

Notes to Table 1:
Abbreviations: ASA, American Society of Anesthesiology; CNS, central nervous system; SIRS, systemic inflammatory response syndrome; ENT, Ear, nose, and throat; MIS, minimally invasive surgery; med, median; IQR, interquartile range.

[a] Requiring nutritional support was reported by NSQIP-P and was defined as any patient receiving enteral feedings or intravenous total parenteral nutrition at the time of the surgical procedure.

[b] Wasted was defined being 2 standard deviations below the average weight for age for children <2 years old, and BMI for age for children ≥2 years old using age and gender stratified CDC growth charts.

[c] Stunted was defined as being more than 2 standard deviations below the average height for age using age and gender stratified CDC growth charts.

[d] Pre-operative albumin 3.0 g per deciliter (g/dL) were categorized as having hypoalbuminemia; only patients with reported lab values were included (n = 63,214).

Table 2
Adjusted associations between malnutrition definitions and post-operative outcomes.

	Requires nutritional support[a]	Wasted[b]	Stunted[c]	Hypoalbuminemia[d,e]
	OR (95% CI)[f]	OR (95% CI)[f]	OR (95% CI)[f]	OR (95% CI)[f]
SSI				
Any SSI	1.27 (1.14–1.40)	0.93 (0.82–1.06)	1.18 (1.09–1.27)	1.18 (1.02–1.39)
Organ space	1.34 (1.13–1.58)	0.91 (0.74–1.11)	1.09 (0.96–1.24)	1.28 (1.04–1.58)
Superficial SSI	1.24 (1.08–1.43)	0.93 (0.77–1.11)	1.23 (1.10–1.37)	1.07 (0.84–1.36)
Deep SSI	1.18 (0.86–1.62)	1.15 (0.91–1.46)	1.15 (0.91–1.46)	1.11 (0.63–1.97)
Other infections				
Pneumonia	2.01 (1.67–2.41)	1.19 (0.95–1.50)	1.23 (1.05–1.43)	1.18 (0.88–1.58)
UTI	1.39 (1.15–1.68)	1.02 (0.80–1.29)	1.29 (1.12–1.49)	0.82 (0.58–1.16)
CLABSI	3.24 (2.19–4.78)	1.16 (0.70–1.95)	0.84 (0.58–1.20)	1.26 (0.82–1.95)
C. difficile	1.53 (1.13–2.07)	1.26 (0.89–1.77)	0.97 (0.75–1.25)	1.67 (1.14–2.45)
Any infection	1.47 (1.36–1.60)	1.00 (0.91–1.11)	1.17 (1.10–1.25)	1.13 (1.00–1.28)
	CIE (95% CI)[e]	**CIE (95% CI)[e]**	**CIE (95% CI)[e]**	**CIE (95% CI)[e]**
Time to surgery, days	10.17 (9.89–10.44)	−1.49 (−1.66 to −1.11)	3.09 (2.91–3.27)	1.07 (0.39–1.74)
LOS after surgery, days	2.63 (2.55–2.72)	0.14 (0.05–0.22)	0.23 (0.17–0.28)	3.32 (3.09–3.54)

Abbreviations: OR, odds ratio; CI, confidence interval; SSI, surgical site infection; UTI, urinary tract infection; CLABSI, central line-associated bloodstream infection; CIE, change in estimate; LOS, length of stay.
[a] Requiring nutritional support was reported by NSQIP-P and was defined as any patient receiving enteral feedings or intravenous total parenteral nutrition at the time of the surgical procedure.
[b] Wasted was defined being 2 standard deviations below the average weight for age for children <2 years old, and BMI for age for children ≥2 years old using age and gender stratified CDC growth charts.
[c] Stunted was defined as being more than 2 standard deviations below the average height for age using age and gender stratified CDC growth charts.
[d] Pre-operative albumin <3.0 g per deciliter (g/dL) were categorized as having hypoalbuminemia; patients with no lab values reported were categorized as having normal albumin levels.
[e] Complete case analyses restricting to 63,214 patients who had albumin labs.
[f] Adjusted for race, ethnicity, gender, age, comorbidities, surgery type, case type, operation time, minimally invasive surgery, wound classification and ASA score; each model only included one malnutrition definition at a time.

Additionally, we found only modest overlap among four definitions of malnutrition. Only 27% of malnourished patients met multiple definitions of malnutrition (10% overall), indicating that these definitions are capturing relatively distinct populations. The impacts of malnutrition on post-operative infection and length of stay after surgery also differed across definitions, further suggesting that these distinct populations also have varying levels of risk for post-operative complications. This study highlights the need for consistent evaluation of pre-operative nutritional status and consideration of a global nutritional assessment for appropriate risk stratification. To our knowledge, this is the first study to evaluate how four distinct definitions of pediatric malnutrition affect post-operative outcomes in a broad population of pediatric surgery patients.

Anthropometrically derived measures of malnutrition had mixed results in their effect on post-operative outcomes. Stunting was associated with increased odds of specific types of infections, such as superficial surgical site infection and pneumonia. This measure was most predictive among older patients. Wasting was not associated with 30-day post-operative infection of any type. These results are consistent with prior studies that have described poorer pediatric post-operative outcomes among children who were stunted and required nutritional support, but not among those who were wasted in patients with Crohn's disease and for gastrointestinal and thoracic surgery [2,3,5]. Other prior work in specific patient populations, and this study more broadly, highlight that using anthropometrically derived malnutrition definitions may have limited utility for pre-operative risk stratification in a US-based pediatric surgery population.

Requiring nutritional support and hypoalbuminemia were strong predictors of poor surgical outcomes. In this study, patients receiving nutritional support had the largest increase in pre-operative time to surgery and more than 2-day increase in length of stay after surgery. Among those receiving nutritional support, the highest odds of infection were for CLABSI which supports the notion that many of these patients are receiving supplemental parenteral nutrition; however, the timing of parental initiation or the indication is unclear from the current dataset. In prior studies of critically ill children and pediatric inflammatory bowel disease patients, parenteral nutritional supplementation was associated with increased infectious complications [26,27]. Additionally,

Table 3
Adjusted associations between malnutrition definitions and post-operative Infection, stratified by age.

	Neonate	Infant	Child	Adolescent
	OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]	OR (95% CI)[a]
Requires nutritional support[b]	1.37 (1.06–1.78)	1.43 (1.25–1.64)	1.45 (1.27–1.67)	1.73 (1.44–2.09)
Wasted[c]	0.92 (0.64–1.30)	1.00 (0.83–1.21)	0.94 (0.79–1.12)	1.01 (0.84–1.22)
Stunted[d]	1.06 (0.78–1.46)	1.08 (0.96–1.21)	1.16 (1.05–1.29)	1.27 (1.11–1.45)
Hypoalbuminemia[e,f]	0.94 (0.66–1.33)	1.06 (0.86–1.30)	1.27 (1.01–1.59)	1.26 (0.96–1.64)

Abbreviations: OR, odds ratio; CI, confidence interval.
[a] Adjusted for race, ethnicity, gender, comorbidities, surgery type, case type, operation time, minimally invasive surgery, wound classification steroid use and ASA score; age-stratified estimates were by estimating the models in each group separately.
[b] Requiring nutritional support was reported by NSQIP-P and was defined as any patient receiving enteral feedings or intravenous total parenteral nutrition at the time of the surgical procedure.
[c] Wasted was defined being 2 standard deviations below the average weight for age for children <2 years old, and BMI for age for children ≥2 years old using age and gender stratified CDC growth charts.
[d] Stunted was defined as being more than 2 standard deviations below the average height for age using age and gender stratified CDC growth charts.
[e] Pre-operative albumin 3.0 g per deciliter (g/dL) were categorized as having hypoalbuminemia; patients with no lab values reported were categorized as having normal albumin levels.
[f] Complete case analysis restricting to 63,214 patients with albumin labs available.

Table 4
Prevalence of having pre-operative albumin tested (irrespective of result), across patient and surgical characteristics.

	Albumin tested, %	No test, %	PD (95% CI)
Overall	22	78	–
Nutritional support[a]			
Requires nutritional support	45	55	0.25 (0.24–0.26)
No support	20	80	0 (ref)
Weight for height[b]			
Wasted	29	71	0.07 (0.06–0.07)
Normal	22	78	0 (ref)
Overweight	22	78	0.00 (0.00–0.02)
Height for age[c]			
Stunted	28	72	0.07 (0.07–0.07)
Normal	21	79	0 (ref)
Tall	29	71	0.00 (0.00–0.01)
Age group			
Neonate	40	60	0.22 (0.21–0.23)
Infant	20	80	0.01 (0.01–0.02)
Child	18	82	0 (ref)
Adolescent	28	72	0.10 (0.09–0.10)
Gender			
Male	24	76	0.02 (0.02–0.02)
Female	21	79	0 (ref)
Admission type			
Elective	16	84	0 (ref)
Emergency	42	58	0.25 (0.25–0.26)
Urgent	42	58	0.25 (0.25–0.26)
Surgery type			
Gastrointestinal	41	59	0.28 (0.27–0.28)
Thoracic	26	74	0.13 (0.12–0.14)
Neurosurgery	21	79	0.07 (0.07–0.08)
Orthopedic	14	86	0 (ref)
ENT	12	88	−0.02 (−0.02 to −0.01)
Plastics	9	91	−0.04 (−0.05 to −0.04)
Urology	9	91	−0.04 (−0.05,-0.04)
Appendectomy	47	53	0.34 (0.33–0.34)
Other	20	80	0.06 (0.06–0.07
Comorbidities[d]			
Ventilator dependence	52	48	0.30 (0.29–0.31)
Oxygen support	51	49	0.30 (0.29–0.31)
Tracheostomy	27	73	0.05 (0.03–0.06)
Airway abnormalities	25	75	0.01 (0.01–0.01)
Chronic lung disease	34	66	−0.01 (−0.01,−0.01)
Asthma	22	78	−0.01 (−0.01,-0.01)
Cardiac	33	67	0.11 (0.11–0.12)
Gastrointestinal	33	67	0.13 (0.13–0.14)
Seizure disorder	30	70	0.08 (0.07–0.09)
Cerebral palsy	22	78	-0.01 (−0.01 to 0.00)
Neuromuscular disorder	26	74	0.04 (0.04–0.05)
Structural CNS abnormality	26	74	0.03 (0.03–0.04)
Hematologic	54	56	0.33 (0.32–0.34)
Diabetes	43	57	0.20 (0.15–0.25)
Immunosuppressed	41	59	0.19 (0.12–0.25)
Kidney disease	34	66	0.11 (0.09–0.13)
Congenital malformation	20	80	−0.04 (−0.04 to −0.03)

Abbreviations: PD, prevalence difference; CI, confidence interval; ENT, Ear, Nose, Throat; CNS, central nervous system.

[a] Requiring nutritional support was reported by NSQIP-P and was defined as any patient receiving enteral feedings or intravenous total parenteral nutrition at the time of the surgical procedure.

[b] Wasted was defined being 2 standard deviations below the average weight for age for children <2 years old, and BMI for age for children ≥2 years old using age and gender stratified CDC growth charts; overweight was defined as being 2 standard deviations above the average.

[c] Stunted was defined as being more than 2 standard deviations below the average height for age using age and gender stratified CDC growth charts; tall was defined as being 2 standard deviations above the average.

[d] Each comorbidity was modeled separately, referent is not having that comorbidity.

adult guidelines for preoperative nutritional supplementation encourage 7–14 days of enteral or parenteral nutrition in patients that will not be negatively impacted by a **delay** in their surgery, and are based on a 3-fold increase in post-operative complications and a 5-fold increase in surgical mortality for malnourished patients [28]; however, none of the infectious risks in our pediatric cohort reached that frequency. Our data suggest that, **regardless of the NSQIP-P definition of pre-operative nutritional status used, the risk of post-operative complications in children do not reach the level of risk seen in malnourished adults.**

One important **limitation** to consider as well is that NSQIP-P does not specify the need for nutritional support as enteral or parenteral nutrition, **nor does it provide data regarding the indication or timing of initiation.** Nutritional supplementation may be necessary for a multitude of reasons (e.g. inability to take oral nutrition, parenteral nutritional dependence for intestinal failure), which makes the directionality and mechanisms of **an association with nutrition supplementation** unclear. For example, nutritional support may be decreasing the risk of post-operative complications from a higher baseline risk among these patients **due to an undetected confounding clinical reason,** and therefore **it is** beneficial. Alternatively, early initiation of parenteral nutrition has been shown to be associated with increased infectious complications in critically ill patients **[26], and unfortunately NSQIP-P does not provide the indication, timing, or route of administration for nutritional support and as such its impact is unclear. The variable for nutritional supplementation** may also be capturing children who do not have chronic malnutrition, and their acute need for nutritional support is associated with a more severe surgical indication. However, regardless of the directionality or causes of this association, nutritional support **for surgical patients** is associated with poorer outcomes and may be a good indicator for risk-stratification in pediatric patients. **Specifically, patients who are not malnourished but ill enough to require nutritional supplementation have a higher risk of postoperative infections, which allows for better counseling of patient caregivers regarding postoperative expectations.** To clarify the role of nutritional supplementation in post-operative morbidity additional studies are needed, with more precise definitions of the type**, route, and timing** of nutritional supplementation provided and indication for initiation. **Alternatively, a prospective randomized trial to identify which patients benefit from nutritional supplementation for preoperative optimization compared to those who may not benefit would clarify this point.**

While albumin has been critiqued as an imprecise measure of malnutrition, hypoalbuminemia has also been previously associated with poor post-operative outcomes among pediatric patients in at least one study [19]. However, we found that pre-operative albumin lab values are not consistently captured in NSQIP-P. Notably, urgent and emergency pediatric admissions were more likely to have pre-operative albumin studies performed, compared to elective hospitalizations. This is likely due to lack of routine albumin testing in elective pediatric surgery, and the inclusion of albumin in a complete metabolic panel. Our results are similar to those seen in adults, which show serum albumin to be a predictor of mortality in acutely ill patients [29–33]. **However, there was little overlap with anthropomorphic measures of malnutrition as only 1024 of 6230 patients with hypoalbuminemia had either stunting, wasting, or both z-scores (16.4%). (See** Fig. 1**) As such, future studies using hypoalbuminemia in NSQIP-P as a surrogate for malnutrition should include additional anthropomorphic measures to clearly identify malnourished patients.**

This study is not without limitations. In our cohort 78% of patients were missing albumin values, and we conducted a complete case analysis that may have induced selection bias as sicker patients would be more likely to have non-missing labs. However, we also conducted an additional sensitivity analysis that imputed all missing values to normal levels to eliminate this bias. This categorization likely resulted in the misclassification of some patients who had hypoalbuminemia as having normal levels, which would be expected to bias results towards the null (i.e. no effect) and would thus give us the lower bound of the relationship between hypoalbuminemia and our post-operative outcomes of interest. Given the consistent observed relationship in both complete case and imputed analyses between hypoalbuminemia as a predictor of negative post-operative outcomes in pediatric patients, irrespective of admission type, screening patients undergoing elective surgery for hypoalbuminemia may provide a more complete picture of their nutritional status when combined with anthropometrically derived measures.

Additionally, as mentioned above the NSQIP-P definition of nutritional support includes both parenteral and enteral supplementation and we were unable to distinguish which type was received in our data. The NSQIP-P database also does not sample pediatric patients treated at adult hospitals and thus may not be representative of pediatric surgery post-operative outcomes in all care settings or generalize to all medical practices. Finally, it is unknown whether the pre-operative nutritional assessment altered the planned procedure (i.e. a patient received an ostomy rather than an anastomosis), and what effect alterations in the surgical plan may have had on the patient-level outcomes. Overall, this was the first large scale quantitative population-based analysis of the impact of different malnutrition indicators on pediatric surgery outcomes. The depth of clinical information captured in NSQIP-P captured a diverse pediatric surgery population and permitted robust confounding control in statistical analyses. The additional sensitivity analyses undertaken were consistent with the main findings.

4. Conclusions

Nutritional status is significantly associated with post-operative infections and other patient outcomes after pediatric surgery; however, the choice of malnutrition definition impacts both the prevalence and post-operative infection risk estimates. Pre-operative nutritional support, stunting, and hypoalbuminemia were the most consistent predictors of post-operative infections. Use of nutritional supplementation is associated with increased time to surgery, and length of stay after surgery, and its impact on outcomes in pediatric patients requires additional study. Anthropometrically derived definitions (e.g. wasting) are not consistently associated with patient outcomes. These findings have implications for patient-level counseling, accurate risk stratification, surgical planning, patient optimization in pediatric surgery.

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