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A New Anthropometric Classification Scheme of Preoperative Nutritional Status in Children

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Abbreviation: ACS-NSQIP-P – American College of Surgeons' National Surgical

Quality Improvement Program Pediatric, ASA – American Society of Anesthesiologists.

ABSTRACT

Objective: The World Health Organization uses anthropometric classification scheme of childhood acute and chronic malnutrition based on low weight for height ("wasting") and height for age ("stunting") respectively. The goal of this study was to evaluate a novel two-axis nutritional classification scheme to: 1) characterize nutritional profiles in children undergoing abdominal surgery; and 2) characterize relationships between preoperative nutritional status and post-operative morbidity.

Design: This was an observational cohort study.

Setting: The setting was 50 hospitals caring for children in North American that participated in the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) Paediatric from 2011 to 2013.

Participants: Children greater than 28 days who underwent major abdominal operations were identified.

Interventions/Main Predictor: The cohort of children was divided into nutritional profile groups based on weight for height and height for age/BMI Z-scores: I) underweight/short, ii) underweight/tall, iii) overweight/short, iv) overweight/tall, and v) non-outliers (controls).

Main Outcome Measures: Multiple variable logistic regressions were used to quantify the association between 30-day morbidity and nutritional profile groups while adjusting for procedure case mix, age and American Society of Anaesthesiologists (ASA) class.

Results: A total of 39,520 cases distributed as follows: underweight/short (656, 2.2%); underweight/tall (252, 0.8%); overweight/short (733, 2.4%); overweight/tall (1,534, 5.1%). Regression analyses revealed increased adjusted odds of composite morbidity

(35%) and re-intervention events (75%) in the underweight/short group, while overweight/short patients had increased adjusted odds of composite morbidity and healthcare associated infection (43%), and re-intervention events (79%) as compared to controls.

Conclusion: Stratification of preoperative nutritional status using a scheme incorporating both weight for height and height for age is feasible. Further research is needed to validate this nutritional risk classification for other surgical procedures in children.

INTRODUCTION

Malnutrition (both over and undernutrition) is prevalent among hospitalized children.[1] A variety of paediatric nutritional screening tools which combine subjective assessment with objective anthropometric measurements reflecting body composition exist.[2-4] There is a clear need to develop valid measures of general nutritional status in children as potentially modifiable risk factors for healthcare outcomes.

Existing anthropometric classification schemes define the nutritional status of children relative to standardized populations into 3 pathologic states: wasting (low weight for height), stunting (low height for age), and overweight/obese (high weight for height or BMI).[5 6] Hospitalized children, especially those who require surgery, may require a more detailed classification system that accounts for both their general nutritional state as well as disease-specific impact on growth, as a predictor of adverse outcomes in response to treatment.

A recent evidence review of nutritional assessment measures and clinical outcomes in children undergoing surgery confirms a gap in valid outcome predictors.[7] A major challenge to anthropometric measurements as reliable predictors of nutritional state in children are the confounding effects of disease and its treatment, or related comorbidities (including congenital anomalies) on weight and stature.

The aim of this study was to create and evaluate a novel, anthropometric measure of preoperative nutritional status using a two-axis classification scheme that incorporates both gender specific weight for height and height for age. The primary objective was to describe the distribution of a large cohort of children undergoing abdominal surgery using this novel two-axis classification scheme. The secondary objective was to determine if specific risk groups had higher odds of postoperative morbidity. We hypothesized that a more detailed classification scheme would identify "at risk" growth patterns that might be overlooked by the classic weight for height/BMI or height for age anthropometric classification.

METHODS

Data source and Patient Sample

This retrospective observational cohort study utilized 2011-2013 American College of Surgeons National Surgical Quality Improvement Program-Paediatric (ACS NSQIP-P) data from 54 participating ACS NSQIP-P hospitals across North America. The dataset includes strictly defined preoperative patient demographic, clinical, and procedural variables, as well as postoperative adverse events. Trained, surgical clinical reviewers collected ACS NSQIP-P data from the medical record, and via follow up including patient/family phone calls in the absence of documented encounters, to ascertain 30-day postoperative morbidity with excellent capture.[7 8]

The inclusion criteria were children from 29 days to 18 years of age undergoing major abdominal procedures at the ACS-NSQIP-P centers in the 2011-2103 as specified by the current procedural terminology (CPT, ©AMA) codes (Supplemental File 1). All major abdominal procedures accrued at participating institutions over the three-year time period were included.

Measures

The main predictor variable was a new categorical five level anthropometric measure of preoperative nutritional status using a two-axis classification scheme that incorporates both gender specific weight for height and height for age. The patient preoperative weight, height, age and gender data in the 2011-13 ACS NSQIP-P dataset were used to calculate gender specific weight for height or BMI and height Z-scores. Z-scores were calculated based on the World Health Organization (WHO)[9] algorithm for children under two years of age (which uses weight for height), and the Centre for Disease Control (CDC) algorithm[10] for children two years of age and older (which uses BMI). The weight for height/BMI and height Z-scores were used to assign children to one of four "dual outlier" groups (Z-scores <-2 or >2 for both weight for height/BMI and height axes) as follows: i) underweight/short, ii) underweight/tall, iii) overweight/short, iv) overweight/tall and v) controls, as shown in Figure 1.

Statistical Analysis

Descriptive counts and frequencies of preoperative clinical and procedural variables as well as postoperative 30-day morbidity for the five nutritional profile groups were calculated. All patient-specific independent variables were dichotomous with the exception of American Society of Anaesthesiologists (ASA) Class, age, race and preoperative sepsis. ASA class was categorized using ASA class I as reference and was treated as a continuous numeric variable in multivariate analysis. Age was categorized as infants < 1year, 1-2 years, 3-5 years, 6-7 years, 8-12 years and 13-18 years. In the multivariate analysis age was treated as a continuous variable. Race was categorized as Caucasian, African American, Asian, Native American and other (which included patients where race was missing) with Caucasian as reference. Preoperative sepsis was categorized as no sepsis, systemic inflammatory response syndrome, sepsis, and septic shock.

The main outcomes were complications occurring within 30-days of surgery including surgical site infection, postoperative sepsis, return to the operating room, wound dehiscence, transfusion within 72 hours, renal failure, pneumonia, cardiac arrest, deep vein thrombosis, urinary tract infection, and mortality. Three binary composite dependent variables were created because the number of patients having any single complication was low. These included: i) Composite Morbidity, defined as one or more of the following: surgical site infection, pneumonia, reintubation, pulmonary embolism, renal insufficiency, urinary tract infection, coma, seizure, peripheral nerve injury, intra-ventricular haemorrhage, intracranial haemorrhage, cardiac arrest, intraoperative and postoperative transfusion within 72 hours, graft failure, venous thrombosis requiring therapy, postoperative sepsis, and central line associated blood stream infection; ii) Healthcare Associated Infection (HAI), defined as one or more of the following: surgical site infection, postoperative sepsis, pneumonia, central line associated infection, and urinary tract infection; and iii) Need for re-intervention, defined as one or more of the following: unplanned reoperation, unplanned reintubation, acute renal failure requiring dialysis, and cardiac arrest. Mortality was not specifically analysed due to the rarity of this occurrence.

Height was missing in 9,483 out of 39,520 children, approximately 24% of the study sample and would have been a major source of bias. The missingness of height was assumed to be random, based on the comparability of preoperative patient variables and postoperative 30-day morbidity between children with or without height records (data not shown). Multiple imputation (a total of 20) using multivariate normal with data augmentation was done to directly impute nutrition profile groups rather than height alone. Weight was missing in <5% of the sample and was dealt with in a similar manner.

Pearson R was calculated for all independent preoperative patient variables and anthropometric Z-scores. Independent preoperative patient variables that were correlated more than 0.7 correlation (either direction) with either preoperative weight for height Z-score or preoperative height Z-score were included as auxiliary variables in the multiple imputation model. The final regression model included 37 independent preoperative patient and procedure variables listed in Supplemental File 2 and adjusted for clustering at the hospital level using random effects. Three models were run for each of the three outcomes. Subsequently, separate logistic regression models with random effects were performed to specifically assess nutrition profile groups as a predictor of composite 30-day morbidity, healthcare associated infection, and re-intervention events, while adjusting for procedure case mix (CPT linear risk) [11], age (as a numeric variable derived from age) and ASA class treated as continuous variables to facilitate model convergence. These variables were selected based on previous studies which demonstrated that they account for the majority of variance in ACS NSQIP-P 30-day morbidity.[12 13]

Two sensitivity analyses were performed. First, all ex-premature children were excluded and the regression analyses repeated, to interrogate potential bias caused by prematurity on growth potential. The second sensitivity analysis excluded all emergency and urgent cases to assess potential bias in favour of higher complication rates associated with emergency cases. The RAND Corporation institutional review board approved this study. All data management and analyses were performed in SAS 9.3 (SAS Institute, Cary NC).

RESULTS

A total of 39,520 children were analysed. Of the 30,037 children with complete anthropometric data, 3,175 children (10.5%) could be categorized into one of four nutritional profile groups defined by dual growth outlier status, for both weight for height or BMI and height for age. The largest outlier category was overweight tall, the smallest outlier category was underweight tall. The scatterplot is depicted in Figure 1, and demonstrates a skewness within the population, with disproportionately more children having negative height Z-scores.

Compared to the other groups, underweight short children had associated risk factors suggesting nutritional vulnerability (highest rates of preoperative nutritional supplementation and weight loss greater than 10% body weight in the six months before surgery), and higher rates of comorbidity (Table 1). These included higher rates of premature birth, oesophageal-gastrointestinal disease, neurologic comorbidity, developmental delay and a history of cardiac surgery. Underweight short children also had higher unadjusted rates of specific adverse outcomes including postoperative sepsis, need for postoperative transfusion and mortality, as well as the highest rates of composite morbidity and need for re-intervention (Table 2).

When controlling for procedure case mix, age, and ASA, underweight short and overweight short children had 35% and 43% increased adjusted odds of 30-day composite morbidity, respectively (Table 3), a finding which persisted when prematurely born children were excluded. However, when urgent/emergent cases were excluded underweight short children no longer had higher adjusted odds of 30 day composite morbidity. Multivariate analysis also revealed that overweight short children had a 43% increased adjusted odds of developing a healthcare associated infection (Table 4). Both underweight short and overweight short children also demonstrated significantly increased adjusted odds of need for re-intervention (75% and 79% respectively; Table 5).

DISCUSSION

In contrast to adults, the evidence of a predictive relationship between nutritional state and healthcare outcomes in children is sparse. The severity of malnutrition assessed with a variety of tools including estimates of energy intake and body composition, serum markers and anthropometric measurements have been shown to have some correlation with outcomes in critically ill children[14 15], and paediatric cardiac surgery patients[16-19], yet no nutrition metric that is generally predictive of outcome for populations of hospitalized children has been identified.

Only a few studies in children undergoing non-cardiac surgery have sought an association between anthropometric classification and postoperative morbidity. Previous studies using the aggregate NSQIP paediatric dataset have shown that children in the ≤5th weight percentile experienced higher rates of postoperative transfusion and reintubation[20], while children undergoing appendectomy[21] and urologic procedures[22] who met BMI percentile definitions of overweight/obese were more likely to experience postoperative wound complications. However, a limitation of existing anthropometric classification schemes is that they were developed to define the nutritional state of an individual relative to a reference population of "healthy" children. Hospitalized children, and notably those undergoing abdominal surgery represent a heterogeneous population, some of whom are healthy with simple surgical conditions like appendicitis, while others have a diverse variety of acute or chronic diseases, often with significant comorbidities who may not conform to the classic malnutrition categories of "wasting" (low weight for height), "stunting" (low height for age) and "overweight/obese (high weight for height or

BMI). Therefore, classification schemes which more accurately capture the effects of nutritional state and underlying disease on growth patterns are required.

The current study demonstrates the feasibility of an anthropometric classification scheme that combines weight for height (or BMI) on the Y-axis and height for age on the X-axis as a means of substratifying outliers into 4 specific body morphologies. Underweight short and overweight short body shapes were independently associated with postoperative composite morbidity and need for re-intervention after controlling for case-mix, age and ASA. Underweight short children also had higher rates of associated disease that could have contributed to their preoperative nutritional state, and likely also had some influence on the occurrence of adverse outcomes. The other distinguishing characteristic of the underweight short group is that 44% experienced > 10% weight loss in the 6 months prior to surgery, and almost 40% received preoperative parenteral or enteral nutritional support, which is likely the best evidence that this group was likely significantly undernourished prior to surgery.

Overweight short patients on the other hand, were at increased risk for all 3 adverse outcomes: composite morbidity, Hospital-Acquired Infection (most commonly surgical site infection) and need for re-intervention. In contrast to the underweight short group, these patients did not have distinguishing comorbidity profiles, and it seems unlikely that chronic undernutrition is responsible for their body shape or their apparent susceptibility to adverse events. Other potential body morphology determinants include endocrine/metabolic disorders, and genetic disorders/congenital anomalies which could disturb musculoskeletal growth leading to reduced stature. Finally, severe acute or chronic inflammatory diseases of the gastrointestinal tract may have confounding effects on both the patient's nutritional state and body morphology (e.g., effects of chronic steroid exposure, total parenteral nutrition, edema from low protein states). Even without knowledge of the specific diagnoses or the operations performed, one can speculate that some combination of the patient's underlying nutritional state, the metabolic/inflammatory activity of the disease requiring surgery and the failure or medical treatments prior to a decision for surgery contribute to the risk of an adverse outcome after surgery, and that body shape patterns may be a proxy for this aggregate risk.

There are several limitations to this study. This was a retrospective secondary data analysis of observational data, and is therefore subject to inherent bias, particularly with regards to missing data. A second limitation is the lack of specificity of the composite morbidity outcomes. Despite the relatively large number of children analysed, the very low rates of post-operative morbidity in children means that the numbers of any individual outcome are small, which increases the probability of type 2 errors. The three composite morbidities intended to capture any 30-day composite morbidity, healthcare associated infections, and re-intervention events are an attempt to create some granularity in the type of morbidity associated with certain nutritional profile groups while allowing modest aggregation.[23] Another limitation is that the ACS NSQIP-P dataset categorizes patients by surgical procedure rather than diagnosis, which limits the discernment of growth disturbances by disease states. Finally, as demonstrated by the high rate of underweight and overweight children, this study focused on a highly select group of children referred to tertiary children's hospitals which have self-selected to participate in

ACS NSQIP-P. As such the findings of this study may not be generalizable to a broader cohort of hospitals or hospitalized children.

This study demonstrates that it is feasible to stratify children into 4 anthropometric risk groups based on height and weight. Two of these groups, underweight short and overweight short had significantly higher adjusted 30-day morbidity rates. Although further validations are required in particularly to establish generalisability outside of hospitalised children undergoing abdominal surgery. This nutritional profile classification could be used to screen children undergoing surgery and therefore identify "at risk" patients, some of whom (e.g. underweight short) might specifically benefit from pre-operative nutritional rehabilitation.

Transparency Statement:
The manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as originally planned

Role of Funding Source:
There was no support from any organisation for the submitted work [or describe if any]; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years [or describe if any], no other relationships or activities that could appear to have influenced the submitted work.

Authors Contributions:
Study conception and design were performed by: Stey, Ricks Skarsgard, Innis
Acquisition of data was performed by: Hall, Rangel, Moss
Analysis and interpretation of data were performed by: Stey, Ricks Skarsgard, Innis, Rangel, Moss, Hall, Dibbins
Drafting of manuscript was performed by: Stey, Ricks, Skarsgard, Innis, Rangel, Moss, Hall, Dibbins
Critical revision was performed by: Stey, Ricks, Skarsgard, Innis, Rangel, Moss, Hall, Dibbins

What is already known on this topic: Nutritional status is an important predictor of health, particularly after surgery and difficult to quantify in children.

What this study adds: This study proposes a stratification of preoperative nutritional status using a scheme incorporating both weight for height and height for age.

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Legend Figure 1: Children from 29 days to 18 years were divided into five nutritional profile groups based on the WHO and CDC growth curve algorithms and plotted by their assigned weight for height Z-score along the Y axis and height Z-score along the X axis. Children outside of two Z-scores in any direction were categorized as an extreme nutritional profile group

Table 1: Preoperative Patient Specific Clinical Variables and Comorbidities by Nutritional Profile Group

Preoperative Clinical Variables	Underweight Short N=656	Overweight Short N=733	Underweight Tall N=252	Overweight Tall N=1,534	Normal N=26,862	*P value
Inpatient Status	585 (89.2)	591 (80.6)	210 (83.3)	1,142 (74.5)	20,280 (75.5)	<0.0001
Case Status						<0.0001
Elective	498 (76.0)	411 (56.1)	98 (38.9)	1,240 (80.8)	14,431 (53.7)	
Urgent	87 (13.3)	151 (20.6)	54 (21.4)	124 (8.1)	4,851 (18.1)	
Emergent	71 (10.9)	171 (23.3)	100 (39.7)	170 (11.1)	7,580 (28.2)	
Male Gender	405 (61.7)	453 (61.8)	156 (61.9)	969 (63.2)	14,911 (55.5)	<0.0001
Race						0.0003
Caucasian	491 (79.2)	567 (81.9)	185 (76.1)	1,240 (81.5)	21,283 (83.8)	
African-American	110 (17.7)	105 (15.2)	49 (20.2)	239 (15.7)	3,289 (13.0)	
Asian	18 (2.9)	18 (2.6)	9 (3.7)	33 (2.2)	661 (2.6)	
Native American	1 (0.2)	2 (0.3)	0	8 (0.5)	120 (0.5)	
Hispanic	63 (9.6)	132 (18.0)	40 (15.9)	199 (13.0)	4,054 (15.1)	0.04
Age						<0.0001
Age 29 days – 364 days	308 (47.0)	225 (30.7)	95 (37.7)	840 (54.8)	5,069 (18.9)	
Age 1 – 2 years	32 (4.9)	127 (17.3)	13 (5.2)	508 (33.1)	1,431 (5.3)	
Age 3 – 5 years	53 (8.1)	122 (16.6)	61 (24.2)	24 (1.6)	3,007 (11.2)	
Age 6 – 7 years	32 (4.9)	45 (6.1)	36 (14.3)	31 (2.0)	2,117 (7.9)	
Age 8 – 12 years	97 (14.9)	114 (15.6)	38 (15.1)	83 (5.4)	6,980 (26.0)	
Age 13 – 18 years	134 (20.4)	100 (13.6)	9 (3.6)	48 (3.1)	8,258 (30.7)	
Premature birth	170 (25.9)	94 (12.8)	14 (5.6)	261 (17.0)	2276 (8.5)	<0.0001
Metabolic & Nutritional Conditions						
Nutritional Support	253 (38.6)	139 (19.0)	29 (11.5)	286 (18.6)	2,515 (9.4)	<0.0001
Greater than 10% weight loss within 6 months	286 (43.6)	72 (9.8)	37 (14.7)	155 (10.1)	1,823 (6.8)	<0.0001
Renal Conditions						
Acute Renal failure	5 (0.8)	3 (0.4)	2 (0.8)	11 (0.7)	126 (0.5)	0.27
American Society of Anesthesiologists Class						
ASA I	33 (5.0)	181 (24.7)	74 (29.4)	275 (17.9)	7,904 (29.4)	<0.0001
ASA II	147 (22.4)	261 (35.6)	111 (44.1)	673 (43.9)	12,044 (44.8)	

ASA III	407 (62.0)	251 (34.2)	59 (23.4)	514 (33.5)	6,294 (23.4)	
ASA IV	65 (9.9)	39 (5.3)	6 (2.4)	66 (4.3)	591 (2.2)	
ASA V	4 (0.6)	1 (0.1)	2 (0.8)	6 (0.4)	29 (0.1)	
Gastrointestinal Conditions						
Esophageal Gastrointestinal Disease	436 (66.5)	331 (45.2)	100 (39.7)	743 (48.4)	8,821 (32.8)	<0.0001
Hepatobiliary Disease	35 (5.3)	36 (4.9)	5 (2.0)	76 (5.0)	2,321 (8.6)	<0.0001
Cardiovascular Conditions						
Cardiac Risk Factors						<0.0001
Mild cardiac risk factors	103 (15.7)	73 (10.0)	5 (2.0)	173 (11.3)	1444 (5.4)	
Moderate cardiac risk factors	55 (8.4)	42 (5.7)	6 (2.4)	72 (4.7)	693 (2.6)	
Severe cardiac risk factors	26 (4.0)	14 (1.9)	1 (0.4)	45 (2.9)	280 (1.0)	
Cardiac Surgery	81 (12.4)	56 (7.6)	9 (3.6)	127 (8.3)	1,086 (4.0)	<0.0001
Neurologic Conditions						
Cerebrovascular Accident	42 (6.4)	30 (4.1)	5 (2.0)	63 (4.1)	509 (1.9)	<0.0001
Seizure Disorder	124 (18.9)	65 (8.9)	20 (7.9)	72 (4.7)	1,110 (4.1)	<0.0001
Cerebral Palsy	112 (17.1)	22 (3.0)	8 (3.2)	16 (1.0)	516 (1.9)	<0.0001
Neuromuscular Disorder	77 (11.7)	45 (6.1)	12 (4.8)	59 (3.9)	844 (3.1)	<0.0001
Developmental delay	263 (40.1)	147 (20.1)	26 (10.3)	249 (16.2)	2,786 (10.4)	<0.0001
CNS Structural Abnormality	127 (19.4)	75 (10.2)	14 (5.6)	156 (10.2)	1,296 (4.8)	<0.0001
Hematologic & Immunologic Conditions						
Bleeding Disorder	11 (1.7)	9 (1.2)	0 (0)	16 (1.0)	223 (0.8)	0.025
Steroid use within 30 days	37 (5.6)	33 (4.5)	4 (1.6)	50 (3.3)	918 (3.4)	0.007
Immune Disease	18 (2.7)	18 (2.5)	0 (0)	19 (1.2)	615 (2.3)	0.69
Hematologic Disorder	64 (9.8)	37 (5.1)	8 (3.2)	73 (4.8)	1,396 (5.2)	0.001
Bone Marrow Transplant	4 (0.6)	2 (0.3)	0	6 (0.4)	79 (0.3)	0.33
Transplantation	4 (0.6)	4 (0.6)	0	3 (0.2)	147 (0.6)	0.61
Preoperative Red Blood Cell Transfusion	25 (3.8)	19 (2.6)	5 (2.0)	23 (1.5)	384 (1.4)	<0.0001
Pulmonary Conditions						
Asthma	43 (6.6)	70 (9.6)	7 (2.8)	81 (5.3)	1,665 (6.2)	0.12
Chronic Lung Disease	92 (14.0)	56 (7.6)	5 (2.0)	112 (7.3)	856 (3.2)	<0.0001
Cystic Fibrosis	8 (1.2)	4 (0.6)	1 (0.4)	7 (0.5)	181 (0.7)	0.52

Structural Pulmonary Abnormality	83 (12.7)	64 (8.7)	11 (4.4)	130 (8.5)	1,078 (4.0)	<0.0001
Oxygen supplementation	70 (10.7)	53 (7.2)	10 (4.0)	96 (6.3)	691 (2.6)	<0.0001
Tracheostomy	18 (2.7)	30 (4.1)	3 (1.2)	37 (2.4)	264 (1.0)	<0.0001
Acuity of Condition						
Prior surgery within 30 days	31 (4.7)	22 (3.0)	10 (4.0)	39 (2.5)	530 (2.0)	<0.0001
Open Wound	22 (3.4)	13 (1.8)	4 (1.6)	40 (2.6)	538 (2.0)	0.07
Cardiopulmonary Resuscitation	2 (0.3)	3 (0.4)	1 (0.4)	2 (0.1)	28 (0.1)	0.006
Do Not Resuscitate	2 (0.3)	0	0	1 (0.1)	21 (0.1)	0.35
Inotropic Support	15 (2.3)	7 (1.0)	2 (0.8)	11 (0.7)	179 (0.7)	<0.0001
Preoperative Sepsis within 48 hours						<0.0001
No sepsis	620 (94.5)	645 (88.0)	205 (81.4)	1,452 (94.7)	23,022 (85.7)	
Systemic Inflammatory Response Syndrome	17 (2.6)	38 (5.2)	16 (6.4)	36 (2.4)	1,980 (7.4)	
Sepsis	13 (2.0)	47 (6.4)	31 (12.3)	39 (2.5)	1,799 (6.7)	
Septic shock	6 (0.9)	3 (0.4)	0 (0)	7 (0.5)	61 (0.2)	

*Derived from Chi-square test of preoperative patient specific clinical variables among nutritional profile groups.

Table 2: Unadjusted Rates of Postoperative 30-day Complication by Nutritional Profile Group

Postoperative 30-day Complications	Underweight Short N=656	Overweight Short N=733	Underweight Tall N=252	Overweight Tall N=1,534	Normal N=26,862	*P Value
Surgical Site Infection	13 (2.0)	34 (4.6)	6 (2.4)	41 (2.7)	913 (3.4)	0.31
Postoperative Sepsis	16 (2.4)	6 (0.8)	1 (0.4)	26 (1.7)	224 (0.8)	0.0002
Return to Operating Room	32 (4.9)	39 (5.3)	5 (2.0)	64 (4.2)	769 (2.9)	<0.0001
Dehiscence	4 (0.6)	6 (0.8)	3 (1.2)	10 (0.7)	111 (0.4)	0.03
Transfusion within 72 hours	16 (2.4)	7 (1.0)	3 (1.2)	19 (1.2)	162 (0.6)	<0.0001
Reintubation	16 (2.4)	5 (0.7)	3 (1.2)	7 (0.5)	106 (0.4)	<0.0001
Acute Renal Failure	2 (0.3)	2 (0.3)	0 (0)	3 (0.2)	34 (0.1)	0.18
Central Line Associated Infection	3 (0.5)	1 (0.1)	0	6 (0.4)	51 (0.2)	0.24
Pneumonia	8 (1.2)	7 (1.0)	2 (0.8)	7 (0.5)	135 (0.5)	0.01
Cardiac Arrest	3 (0.5)	1 (0.1)	1 (0.4)	5 (0.3)	35 (0.1)	0.02
Deep Vein Thrombosis	1 (0.2)	1 (0.1)	1 (0.4)	4 (0.3)	56 (0.2)	0.82
Urinary Tract Infections	4 (0.6)	5 (0.7)	0 (0)	11 (0.7)	155 (0.6)	0.84
Mortality	4 (0.6)	3 (0.4)	1 (0.4)	5 (0.3)	51 (0.2)	0.005
Composite 30-day Morbidity	66 (10.1)	61 (8.3)	20 (7.9)	107 (7.0)	1,634 (6.1)	<0.0001
Healthcare associated Infections	34 (5.2)	46 (6.3)	9 (3.6)	79 (5.2)	1,287 (4.8)	0.18
Re-intervention events	48 (7.3)	43 (5.9)	8 (3.2)	71 (4.6)	881 (3.3)	<0.0001

*Derived from a chi-square test comparing complications among nutritional profile group

Table 3: Multivariate Logistic Regression Predicting Composite 30-day Morbidity

	Odds Ratio*	95% Confidence Interval*	P value*
Composite Morbidity CPT Linear Risk	0.38	0.36-0.40	<0.0001
Age	0.99	0.98-1.00	0.07
ASA Class	1.02	1.00-1.04	0.06
Underweight Short	1.35	1.03-1.75	0.04
Overweight Short	1.43	1.06-1.89	0.01
Underweight Tall	1.32	0.81-2.22	0.30
Overweight Tall	1.00	0.81-1.25	0.97

Both composite 30-day morbidity CPT linear risk and age were continuous variables. *Derived from Proc Mianalyze following multiple imputation of the four nutritional profile groups using Proc Glimmix.

Table 4: Multivariate Logistic Regression Predicting Composite Healthcare associated Infections

	Odds Ratio*	95% Confidence Interval*	P value*
Composite HAI CPT Linear Risk	0.33	0.30-0.36	<0.0001
Age	0.98	0.97-0.99	0.0001
ASA Class	1.05	1.02-1.08	<0.0001
Underweight Short	0.89	0.60-1.33	0.56
Overweight Short	1.43	1.05-1.92	0.02
Underweight Tall	0.75	0.37-1.52	0.42
Overweight Tall	1.15	0.90-1.45	0.27

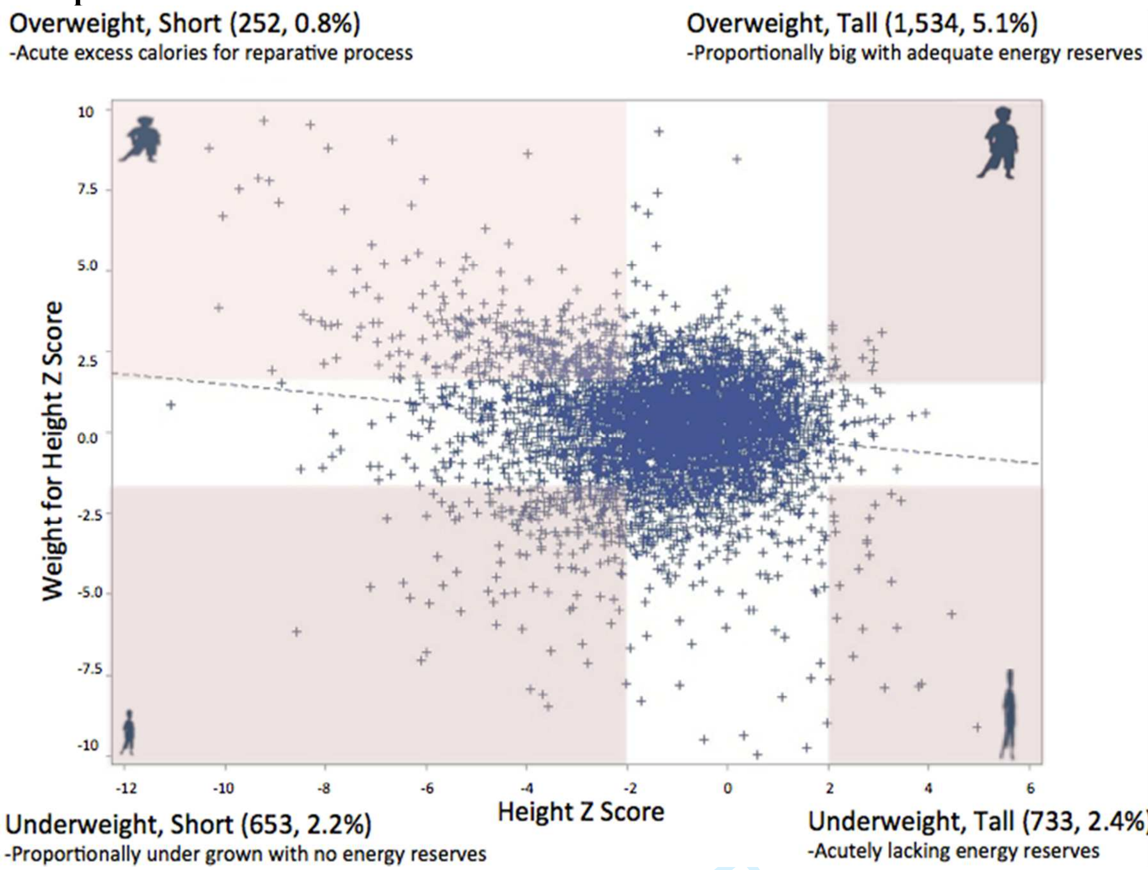
Both composite healthcare associated infection CPT linear risk and age were continuous variables. *Derived from Proc Mianalyze following multiple imputation of the four nutritional profile groups using Proc Glimmix.

Table 5: Multivariate Logistic Regression Predicting Composite Re-intervention Events

	Odds Ratio*	95% Confidence Interval*	P value*
Composite RIE CPT Linear Risk	0.34	0.31-0.36	<0.0001
Age	0.99	0.98-1.00	0.28
ASA Class	1.01	0.98-1.01	0.35
Underweight Short	1.75	1.28-2.38	0.001
Overweight Short	1.79	1.30-2.50	0.001
Underweight Tall	0.99	0.47-2.08	0.97
Overweight Tall	1.08	0.82-1.41	0.58

Both composite re-intervention events CPT linear risk and age were continuous variables. *Derived from Proc Mianalyze following multiple imputation of the four nutritional profile groups using Proc Glimmix.

Figure 1: Anthropometric Scatterplot of Study Sample & Division into Nutritional Profile Groups



Legend Figure 1: Children from 29 days to 18 years were divided into five nutritional profile groups based on the WHO and CDC growth curve algorithms and plotted by their assigned weight for height Z-score along the Y axis and height Z-score along the X axis. Children outside of two Z-scores in any direction were categorized as an extreme nutritional profile group

Supplemental File 1: Major abdominal cases accrued in ACS-NSQIP-P

CPT	PROCEDURE DESCRIPTION
22900	Abdominal Wall Tumor Excision
37181-38120	Splenic Procedures
38562-38780	Lymphadenectomy
39502	Paraesophageal Hernia Repair
43280-43326	Fundoplication
43520-43840	Gastric Procedures
44005	Lysis of Adhesions
44010-44025	Enterotomy
44050	Reduction of Volvulus, Intussusception or Internal Hernia
44055	Ladd Procedure
44110-46748	Bowel Resection and Ostomy
47100-47130	Liver Resection
47480-47620	Cholecystectomy
47700-47800	Biliary Procedures
48120-48146	Pancreatic Resection
35840, 49000-49322	Abdominal Exploration)
49324-49421	Peritoneal Dialysis Catheter Placement
49600-49611	Omphalocele Repair
50205	Renal Biopsy
50220-50548	Nephrectomy
51500	Urachal Cyst Excision
51530-51585	Cystostomy and Cystectomy
57106-57112	Vaginectomy

Supplemental File 2: Auxiliary independent preoperative patient and procedure variables used in the multiple imputation model

Procedure case mix CPT code linear risk variable
Inpatient Status
Case Status
Elective
Urgent
Emergent
Male Gender
Hispanic
Age
Age 29 days – 364 days
Age 1 – 2 years
Age 3 – 5 years
Age 6 – 7 years
Age 8 – 12 years
Age 13 – 18 years
Premature birth
Metabolic & Nutritional Conditions
Parenteral and enteral nutritional Support
Greater than 10% weight loss within 6 months
Nutritional Profile Groups
Underweight Short
Overweight Short
Underweight Tall
Overweight Tall
Normal
Renal Conditions
Acute Renal failure
American Society of Anesthesiologists Class
ASA I
ASA II
ASA III
ASA IV
ASA V
Gastrointestinal Conditions
Esophageal Gastrointestinal Disease
Hepatobiliary Disease
Cardiovascular Conditions
Cardiac Surgery
Neurologic Conditions
Cerebrovascular Accident
Seizure Disorder
Cerebral Palsy
Neuromuscular Disorder

Developmental delay
CNS Structural Abnormality
Hematologic & Immunologic Conditions
Bleeding Disorder
Steroid use within 30 days
Immune Disease
Hematologic Disorder
Bone Marrow Transplant
Transplantation
Preoperative Red Blood Cell Transfusion
Pulmonary Conditions
Asthma
Chronic Lung Disease
Cystic Fibrosis
Structural Pulmonary Abnormality
Oxygen supplementation
Tracheostomy
Acuity of Condition
Prior surgery within 30 days
Open Wound
Cardiopulmonary Resuscitation
Do Not Resuscitate
Inotropic Support
Preoperative Sepsis within 48 hours
No sepsis
Systemic Inflammatory Response Syndrome
Sepsis
Septic shock

These variables were included in hierarchical Multiple imputation model.

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A New Anthropometric Classification Scheme of Preoperative Nutritional Status in Children; A Retrospective Observational Cohort Study

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Abbreviation: ACS-NSQIP-P – American College of Surgeons' National Surgical Quality Improvement Program Pediatric, ASA – American Society of Anesthesiologists.

ABSTRACT

Objective: The World Health Organization uses anthropometric classification scheme of childhood acute and chronic malnutrition based on low BMI ("wasting") and height for age ("stunting") respectively. The goal of this study was to describe a novel two-axis nutritional classification scheme to: 1) characterize nutritional profiles in children undergoing abdominal surgery; and 2) characterize relationships between preoperative nutritional status and post-operative morbidity.

Design: This was a retrospective observational cohort study.

Setting: The setting was 50 hospitals caring for children in North American that participated in the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) Paediatric from 2011 to 2013.

Participants: Children greater than 28 days who underwent major abdominal operations were identified.

Interventions/Main Predictor: The cohort of children was divided into nutritional profile groups based on BMI and height for age Z-scores: I) underweight/short, ii) underweight/tall, iii) overweight/short, iv) overweight/tall, and v) non-outliers (controls).

Main Outcome Measures: Multiple variable logistic regressions were used to quantify the association between 30-day morbidity and nutritional profile groups while adjusting for procedure case mix, age and American Society of Anaesthesiologists (ASA) class.

Results: A total of 39,520 cases distributed as follows: underweight/short (656, 2.2%); underweight/tall (252, 0.8%); overweight/short (733, 2.4%); overweight/tall (1,534, 5.1%). Regression analyses revealed increased adjusted odds of composite morbidity (35%) and re-intervention events (75%) in the underweight/short group, while overweight/short patients had increased adjusted odds of composite morbidity and healthcare associated infection (43%), and re-intervention events (79%) as compared to controls.

Conclusion: Stratification of preoperative nutritional status using a scheme incorporating both BMI and height for age is feasible. Further research is needed to validate this nutritional risk classification for other surgical procedures in children.

INTRODUCTION

Malnutrition (both over and undernutrition) is prevalent among hospitalized children.[1] A variety of paediatric nutritional screening tools which combine subjective assessment with objective anthropometric measurements reflecting body composition exist.[2-4] There is a clear need to develop valid measures of general nutritional status in children as potentially modifiable risk factors for healthcare outcomes.

Existing anthropometric classification schemes define the nutritional status of children relative to standardized populations into 3 pathologic states: wasting (low BMI), stunting (low height for age), and overweight/obese (high BMI).[5 6] Hospitalized children, especially those who require surgery, may require a more detailed classification system that accounts for both their general nutritional state as well as disease-specific impact on growth, as a predictor of adverse outcomes in response to treatment.

A recent evidence review of nutritional assessment measures and clinical outcomes in children undergoing surgery confirms a gap in valid outcome predictors.[7] A major challenge to anthropometric measurements as reliable predictors of nutritional state in children are the confounding effects of disease and its treatment, or related comorbidities (including congenital anomalies) on weight and stature.

The aim of this study was to create and describe a novel, anthropometric measure of preoperative nutritional status using a two-axis classification scheme that incorporates both gender specific BMI and height for age. The primary objective was to describe the distribution of a large cohort of children undergoing abdominal surgery using this novel two-axis classification scheme. The secondary objective was to determine if specific risk groups had higher odds of postoperative morbidity. We hypothesized that a more detailed classification scheme would identify "at risk" growth patterns that might be overlooked by the classic BMI or height for age anthropometric classification.

METHODS

Data source and Patient Sample

This retrospective observational cohort study utilized 2011-2013 American College of Surgeons National Surgical Quality Improvement Program-Paediatric (ACS NSQIP-P) data from 54 participating ACS NSQIP-P hospitals across North America. The dataset includes strictly defined preoperative patient demographic, clinical, and procedural variables, as well as postoperative adverse events. Trained, surgical clinical reviewers collected ACS NSQIP-P data from the medical record, and via follow up including patient/family phone calls in the absence of documented encounters, to ascertain 30-day postoperative morbidity with excellent capture.[7 8]

The inclusion criteria were children from 29 days to 18 years of age undergoing major abdominal procedures at the ACS-NSQIP-P centers in the 2011-2103 as specified by the current procedural terminology (CPT, ©AMA) codes (Supplemental File 1). All major abdominal procedures accrued at participating institutions over the three-year time period were included.

Measures

The main predictor variable was a new categorical five level anthropometric measure of preoperative nutritional status using a two-axis classification scheme that incorporates both gender specific BMI and height for age. The patient preoperative weight, height, age and gender data in the 2011-13 ACS NSQIP-P dataset were used to calculate gender specific BMI and height Z-scores. Z-scores were calculated based on the

World Health Organization (WHO)[9] algorithm for children under two years of age BMI Z-score, which in these children is based on recumbent length rather than stature. The Centre for Disease Control (CDC) algorithm[10] for children two years of age and older (which uses BMI). The BMI and height Z-scores were used to assign children to one of four "dual outlier" groups (Z-scores <-2 or >2 for both BMI and height axes) as follows: i) underweight/short, ii) underweight/tall, iii) overweight/short, iv) overweight/tall and v) controls, as shown in Figure 1.

Statistical Analysis

Descriptive counts and frequencies of preoperative clinical and procedural variables as well as postoperative 30-day morbidity for the five nutritional profile groups were calculated. All patient-specific independent variables were dichotomous with the exception of American Society of Anaesthesiologists (ASA) Class, age, race and preoperative sepsis. ASA class was categorized using ASA class I as reference and was treated as a continuous numeric variable in multivariate analysis. Age was categorized as infants < 1year, 1-2 years, 3-5 years, 6-7 years, 8-12 years and 13-18 years. In the multivariate analysis age was treated as a continuous variable. Race was categorized as Caucasian, African American, Asian, Native American and other (which included patients where race was missing) with Caucasian as reference. Preoperative sepsis was categorized as no sepsis, systemic inflammatory response syndrome, sepsis, and septic shock.

The main outcomes were complications occurring within 30-days of surgery including surgical site infection, postoperative sepsis, return to the operating room, wound dehiscence, transfusion within 72 hours, renal failure, pneumonia, cardiac arrest, deep vein thrombosis, urinary tract infection, and mortality. Three binary composite dependent variables were created because the number of patients having any single complication was low. These included: i) Composite Morbidity, defined as one or more of the following: surgical site infection, pneumonia, reintubation, pulmonary embolism, renal insufficiency, urinary tract infection, coma, seizure, peripheral nerve injury, intra-ventricular haemorrhage, intracranial haemorrhage, cardiac arrest, intraoperative and postoperative transfusion within 72 hours, graft failure, venous thrombosis requiring therapy, postoperative sepsis, and central line associated blood stream infection; ii) Healthcare Associated Infection (HAI), defined as one or more of the following: surgical site infection, postoperative sepsis, pneumonia, central line associated infection, and urinary tract infection; and iii) Need for re-intervention, defined as one or more of the following: unplanned reoperation, unplanned reintubation, acute renal failure requiring dialysis, and cardiac arrest. Mortality was not specifically analysed due to the rarity of this occurrence.

Height was missing in 9,483 out of 39,520 children, approximately 24% of the study sample and would have been a major source of bias. The missingness of height was assumed to be random, based on the comparability of preoperative patient variables and postoperative 30-day morbidity between children with or without height records (data not shown). Multiple imputation (a total of 20) using multivariate normal with data augmentation was done to directly impute nutrition profile groups rather than height alone. Weight was missing in <5% of the sample and was dealt with in a similar manner.

Pearson R was calculated for all independent preoperative patient variables and anthropometric Z-scores. Independent preoperative patient variables that were correlated more than 0.7 correlation (either direction) with either preoperative BMI Z-score or preoperative height Z-score were included as auxiliary variables in the multiple imputation model. The final regression model included 37 independent preoperative patient and procedure variables listed in Supplemental File 2 and adjusted for clustering at the hospital level using random effects. Three models were run for each of the three outcomes. Subsequently, separate logistic regression models with random effects were performed to specifically assess nutrition profile groups as a predictor of composite 30-day morbidity, healthcare associated infection, and re-intervention events, while adjusting for procedure case mix (CPT linear risk) [11], age (as a numeric variable derived from age) and ASA class treated as continuous variables to facilitate model convergence. These variables were selected based on previous studies which demonstrated that they account for the majority of variance in ACS NSQIP-P 30-day morbidity.[12 13]

Two sensitivity analyses were performed. First, all ex-premature children were excluded and the regression analyses repeated, to interrogate potential bias caused by prematurity on growth potential. The second sensitivity analysis excluded all emergency and urgent cases to assess potential bias in favour of higher complication rates associated with emergency cases. The RAND Corporation institutional review board approved this study. All data management and analyses were performed in SAS 9.3 (SAS Institute, Cary NC).

RESULTS

A total of 39,520 children were analysed. Of the 30,037 children with complete anthropometric data, 3,175 children (10.5%) could be categorized into one of four nutritional profile groups defined by dual growth outlier status, for both BMI and height for age. The largest outlier category was overweight tall, the smallest outlier category was underweight tall. The scatterplot is depicted in Figure 1, and demonstrates a skewness within the population, with disproportionately more children having negative height Z-scores.

Compared to the other groups, underweight short children had associated risk factors suggesting nutritional vulnerability (highest rates of preoperative nutritional supplementation and weight loss greater than 10% body weight in the six months before surgery), and higher rates of comorbidity (Table 1). These included higher rates of premature birth, oesophageal-gastrointestinal disease, neurologic comorbidity, developmental delay and a history of cardiac surgery. Underweight short children also had higher unadjusted rates of specific adverse outcomes including postoperative sepsis, need for postoperative transfusion and mortality, as well as the highest rates of composite morbidity and need for re-intervention (Table 2).

When controlling for procedure case mix, age, and ASA, underweight short and overweight short children had 35% and 43% increased adjusted odds of 30-day composite morbidity compared to children who were within 2 Z-scores of mean BMI and height, respectively (Table 3), a finding which persisted when prematurely born children were excluded. However, when urgent/emergent cases were excluded underweight short children no longer had higher adjusted odds of 30 day composite morbidity. Multivariate analysis also revealed that overweight short children had a 43% increased adjusted odds of developing a healthcare associated infection compared to children who were within 2 Z-scores of mean BMI and height (Table 4). Both underweight short and overweight short children also demonstrated significantly increased adjusted odds of need for re-intervention compared to children who were within 2 Z-scores of mean BMI and height (75% and 79% respectively; Table 5).

Adding the anthropometric measure to procedure case mix, age and ASA for modeling composite morbidity increased the area under the receiver operating characteristic curve from 0.70 to 0.71. Similarly, the anthropometric measure added to the procedure case mix, age and ASA for modeling healthcare associated infection increased the area under the receiver operating characteristic curve from 0.67 to 0.68. The area under the receiver operating curve did not change with the addition of anthropometric measures for reinterventions, 0.73 to 0.73.

DISCUSSION

In contrast to adults, the evidence of a predictive relationship between nutritional state and healthcare outcomes in children is sparse. The severity of malnutrition assessed with a variety of tools including estimates of energy intake and body composition, serum markers and anthropometric measurements have been shown to have some correlation with outcomes in critically ill children[14 15], and paediatric cardiac surgery patients[16-19], yet no nutrition metric that is generally predictive of outcome for populations of hospitalized children has been identified.

Only a few studies in children undergoing non-cardiac surgery have sought an association between anthropometric classification and postoperative morbidity. Previous studies using the aggregate NSQIP paediatric dataset have shown that children in the ≤5th weight percentile experienced higher rates of postoperative transfusion and reintubation[20], while children undergoing appendectomy[21] and urologic procedures[22] who met BMI percentile definitions of overweight/obese were more likely to experience postoperative wound complications. However, a limitation of existing anthropometric classification schemes is that they were developed to define the nutritional state of an individual relative to a reference population of "healthy" children. Hospitalized children, and notably those undergoing abdominal surgery represent a heterogeneous population, some of whom are healthy with simple surgical conditions like appendicitis, while others have a diverse variety of acute or chronic diseases, often with significant comorbidities who may not conform to the classic malnutrition categories of "wasting" (low BMI), "stunting" (low height for age) and "overweight/obese (high BMI). Therefore, classification schemes which more accurately capture the effects of nutritional state and underlying disease on growth patterns are required.

The current study demonstrates the feasibility of an anthropometric classification scheme that combines BMI on the Y-axis and height for age on the X-axis as a means of substratifying outliers into 4 specific body morphologies. Underweight short and overweight short body shapes were independently associated with postoperative composite morbidity and need for re-intervention after controlling for case-mix, age and ASA. Underweight short children also had higher rates of associated disease that could have contributed to their preoperative nutritional state, and likely also had some influence on the occurrence of adverse outcomes. The other distinguishing characteristic of the underweight short group is that 44% experienced > 10% weight loss in the 6 months prior to surgery, and almost 40% received preoperative parenteral or enteral nutritional support, which is likely the best evidence that this group was likely significantly undernourished prior to surgery.

Overweight short patients on the other hand, were at increased risk for all 3 adverse outcomes: composite morbidity, Hospital-Acquired Infection (most commonly surgical site infection) and need for re-intervention. In contrast to the underweight short group, these patients did not have distinguishing comorbidity profiles, and it seems unlikely that chronic undernutrition is responsible for their body shape or their apparent susceptibility to adverse events. Other potential body morphology determinants include endocrine/metabolic disorders, and genetic disorders/congenital anomalies which could disturb musculoskeletal growth leading to reduced stature. Finally, severe acute or chronic inflammatory diseases of the gastrointestinal tract may have confounding effects on both the patient's nutritional state and body morphology (e.g., effects of chronic steroid exposure, total parenteral nutrition, edema from low protein states). Even without knowledge of the specific diagnoses or the operations performed, one can speculate that some combination of the patient's underlying nutritional state, the metabolic/inflammatory activity of the disease requiring surgery and the failure or medical treatments prior to a decision for surgery contribute to the risk of an adverse outcome after surgery, and that body shape patterns may be a proxy for this aggregate risk.

There are several limitations to this study. This was a retrospective secondary data analysis of observational data, and is therefore subject to inherent bias, particularly with regards to missing data. A second limitation is the lack of specificity of the composite morbidity outcomes. Despite the relatively large number of children analysed, the very low rates of post-operative morbidity in children means that the numbers of any individual outcome are small, which increases the probability of type 2 errors. The three composite morbidities intended to capture any 30-day composite morbidity, healthcare associated infections, and re-intervention events are an attempt to create some granularity in the type of morbidity associated with certain nutritional profile groups while allowing modest aggregation.[23] Another limitation is that the ACS NSQIP-P dataset categorizes patients by surgical procedure rather than diagnosis, which limits the discernment of growth disturbances by disease states. A third limitation is the assumption that the height data are missing at random and the use of multiple imputation. This could have quite a large effect on our outcomes and may limit our ability to predict different outcomes based on a score where a portion of the primary predictor was imputed. Finally, as demonstrated by the high rate of underweight and overweight children, this study focused on a highly select group of children referred to tertiary children's hospitals which have self-selected to participate in ACS NSQIP-P. As such the findings of this study may not be generalizable to a broader cohort of hospitals or hospitalized children.

This study demonstrates that it is feasible to stratify children into 4 anthropometric risk groups based on height and weight. Two of these groups, underweight short and overweight short had significantly higher adjusted 30-day morbidity rates. Although further validations are required in particularly to establish generalisability outside of hospitalised children undergoing abdominal surgery. This nutritional profile classification could be used to screen children undergoing surgery and therefore identify "at risk" patients, some of whom (e.g. underweight short) might specifically benefit from pre-operative nutritional rehabilitation.

Transparency Statement:

The manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as originally planned

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Authors Contributions:

Study conception and design were performed by: Stey, Ricks Skarsgard, Innis

Acquisition of data was performed by: Hall, Rangel, Moss

Analysis and interpretation of data were performed by: Stey, Ricks Skarsgard, Innis, Rangel, Moss, Hall, Dibbins

Drafting of manuscript was performed by: Stey, Ricks, Skarsgard, Innis, Rangel, Moss, Hall, Dibbins

Critical revision was performed by: Stey, Ricks, Skarsgard, Innis, Rangel, Moss, Hall, Dibbins

What is already known on this topic: Nutritional status is an important predictor of health, particularly after surgery and difficult to quantify in children.

What this study adds: This study proposes a stratification of preoperative nutritional status using a scheme incorporating both BMI and height for age and using this system suggests that underweight short and overweight short children appear to be at greatest risk of post-operative morbidity.

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Legend Figure 1a & 1b: Children from 29 days to 18 years were divided into five nutritional profile groups based on the WHO and CDC growth curve algorithms and plotted by their assigned BMI Z-score along the Y axis and height Z-score along the X axis. Children outside of two Z-scores in any direction were categorized as an extreme nutritional profile group. Figure 1a depicts children under 2 years of age using the WHO algorithm to assign Z-scores. Figure 1b depicts children 2 years of age and older using the CDC algorithm to assign Z-scores.

Table 1: Preoperative Patient Specific Clinical Variables and Comorbidities by Nutritional Profile Group

Preoperative Clinical Variables	Underweight Short N=656	Overweight Short N=733	Underweight Tall N=252	Overweight Tall N=1,534	Normal N=26,862	*P value
Inpatient Status	585 (89.2)	591 (80.6)	210 (83.3)	1,142 (74.5)	20,280 (75.5)	<0.0001
Case Status						<0.0001
Elective	498 (76.0)	411 (56.1)	98 (38.9)	1,240 (80.8)	14,431 (53.7)	
Urgent	87 (13.3)	151 (20.6)	54 (21.4)	124 (8.1)	4,851 (18.1)	
Emergent	71 (10.9)	171 (23.3)	100 (39.7)	170 (11.1)	7,580 (28.2)	
Male Gender	405 (61.7)	453 (61.8)	156 (61.9)	969 (63.2)	14,911 (55.5)	<0.0001
Race						0.0003
Caucasian	491 (79.2)	567 (81.9)	185 (76.1)	1,240 (81.5)	21,283 (83.8)	
African-American	110 (17.7)	105 (15.2)	49 (20.2)	239 (15.7)	3,289 (13.0)	
Asian	18 (2.9)	18 (2.6)	9 (3.7)	33 (2.2)	661 (2.6)	
Native American	1 (0.2)	2 (0.3)	0	8 (0.5)	120 (0.5)	
Hispanic	63 (9.6)	132 (18.0)	40 (15.9)	199 (13.0)	4,054 (15.1)	0.04
Age						<0.0001
Age 29 days – 364 days	308 (47.0)	225 (30.7)	95 (37.7)	840 (54.8)	5,069 (18.9)	
Age 1 – 2 years	32 (4.9)	127 (17.3)	13 (5.2)	508 (33.1)	1,431 (5.3)	
Age 3 – 5 years	53 (8.1)	122 (16.6)	61 (24.2)	24 (1.6)	3,007 (11.2)	
Age 6 – 7 years	32 (4.9)	45 (6.1)	36 (14.3)	31 (2.0)	2,117 (7.9)	
Age 8 – 12 years	97 (14.9)	114 (15.6)	38 (15.1)	83 (5.4)	6,980 (26.0)	
Age 13 – 18 years	134 (20.4)	100 (13.6)	9 (3.6)	48 (3.1)	8,258 (30.7)	
Premature birth	170 (25.9)	94 (12.8)	14 (5.6)	261 (17.0)	2276 (8.5)	<0.0001
Metabolic & Nutritional Conditions						
Nutritional Support	253 (38.6)	139 (19.0)	29 (11.5)	286 (18.6)	2,515 (9.4)	<0.0001
Greater than 10% weight loss within 6 months	286 (43.6)	72 (9.8)	37 (14.7)	155 (10.1)	1,823 (6.8)	<0.0001
Renal Conditions						
Acute Renal failure	5 (0.8)	3 (0.4)	2 (0.8)	11 (0.7)	126 (0.5)	0.27
American Society of Anesthesiologists Class						
ASA I	33 (5.0)	181 (24.7)	74 (29.4)	275 (17.9)	7,904 (29.4)	<0.0001
ASA II	147 (22.4)	261 (35.6)	111 (44.1)	673 (43.9)	12,044 (44.8)	

ASA III	407 (62.0)	251 (34.2)	59 (23.4)	514 (33.5)	6,294 (23.4)	
ASA IV	65 (9.9)	39 (5.3)	6 (2.4)	66 (4.3)	591 (2.2)	
ASA V	4 (0.6)	1 (0.1)	2 (0.8)	6 (0.4)	29 (0.1)	
Gastrointestinal Conditions						
Esophageal Gastrointestinal Disease	436 (66.5)	331 (45.2)	100 (39.7)	743 (48.4)	8,821 (32.8)	<0.0001
Hepatobiliary Disease	35 (5.3)	36 (4.9)	5 (2.0)	76 (5.0)	2,321 (8.6)	<0.0001
Cardiovascular Conditions						
Cardiac Risk Factors						<0.0001
Mild cardiac risk factors	103 (15.7)	73 (10.0)	5 (2.0)	173 (11.3)	1444 (5.4)	
Moderate cardiac risk factors	55 (8.4)	42 (5.7)	6 (2.4)	72 (4.7)	693 (2.6)	
Severe cardiac risk factors	26 (4.0)	14 (1.9)	1 (0.4)	45 (2.9)	280 (1.0)	
Cardiac Surgery	81 (12.4)	56 (7.6)	9 (3.6)	127 (8.3)	1,086 (4.0)	<0.0001
Neurologic Conditions						
Cerebrovascular Accident	42 (6.4)	30 (4.1)	5 (2.0)	63 (4.1)	509 (1.9)	<0.0001
Seizure Disorder	124 (18.9)	65 (8.9)	20 (7.9)	72 (4.7)	1,110 (4.1)	<0.0001
Cerebral Palsy	112 (17.1)	22 (3.0)	8 (3.2)	16 (1.0)	516 (1.9)	<0.0001
Neuromuscular Disorder	77 (11.7)	45 (6.1)	12 (4.8)	59 (3.9)	844 (3.1)	<0.0001
Developmental delay	263 (40.1)	147 (20.1)	26 (10.3)	249 (16.2)	2,786 (10.4)	<0.0001
CNS Structural Abnormality	127 (19.4)	75 (10.2)	14 (5.6)	156 (10.2)	1,296 (4.8)	<0.0001
Hematologic & Immunologic Conditions						
Bleeding Disorder	11 (1.7)	9 (1.2)	0 (0)	16 (1.0)	223 (0.8)	0.025
Steroid use within 30 days	37 (5.6)	33 (4.5)	4 (1.6)	50 (3.3)	918 (3.4)	0.007
Immune Disease	18 (2.7)	18 (2.5)	0 (0)	19 (1.2)	615 (2.3)	0.69
Hematologic Disorder	64 (9.8)	37 (5.1)	8 (3.2)	73 (4.8)	1,396 (5.2)	0.001
Bone Marrow Transplant	4 (0.6)	2 (0.3)	0	6 (0.4)	79 (0.3)	0.33
Transplantation	4 (0.6)	4 (0.6)	0	3 (0.2)	147 (0.6)	0.61
Preoperative Red Blood Cell Transfusion	25 (3.8)	19 (2.6)	5 (2.0)	23 (1.5)	384 (1.4)	<0.0001
Pulmonary Conditions						
Asthma	43 (6.6)	70 (9.6)	7 (2.8)	81 (5.3)	1,665 (6.2)	0.12
Chronic Lung Disease	92 (14.0)	56 (7.6)	5 (2.0)	112 (7.3)	856 (3.2)	<0.0001
Cystic Fibrosis	8 (1.2)	4 (0.6)	1 (0.4)	7 (0.5)	181 (0.7)	0.52

Structural Pulmonary Abnormality	83 (12.7)	64 (8.7)	11 (4.4)	130 (8.5)	1,078 (4.0)	<0.0001
Oxygen supplementation	70 (10.7)	53 (7.2)	10 (4.0)	96 (6.3)	691 (2.6)	<0.0001
Tracheostomy	18 (2.7)	30 (4.1)	3 (1.2)	37 (2.4)	264 (1.0)	<0.0001
Acuity of Condition						
Prior surgery within 30 days	31 (4.7)	22 (3.0)	10 (4.0)	39 (2.5)	530 (2.0)	<0.0001
Open Wound	22 (3.4)	13 (1.8)	4 (1.6)	40 (2.6)	538 (2.0)	0.07
Cardiopulmonary Resuscitation	2 (0.3)	3 (0.4)	1 (0.4)	2 (0.1)	28 (0.1)	0.006
Do Not Resuscitate	2 (0.3)	0	0	1 (0.1)	21 (0.1)	0.35
Inotropic Support	15 (2.3)	7 (1.0)	2 (0.8)	11 (0.7)	179 (0.7)	<0.0001
Preoperative Sepsis within 48 hours						<0.0001
No sepsis	620 (94.5)	645 (88.0)	205 (81.4)	1,452 (94.7)	23,022 (85.7)	
Systemic Inflammatory Response Syndrome	17 (2.6)	38 (5.2)	16 (6.4)	36 (2.4)	1,980 (7.4)	
Sepsis	13 (2.0)	47 (6.4)	31 (12.3)	39 (2.5)	1,799 (6.7)	
Septic shock	6 (0.9)	3 (0.4)	0 (0)	7 (0.5)	61 (0.2)	

*Derived from Chi-square test of preoperative patient specific clinical variables among nutritional profile groups.

Table 2: Unadjusted Rates of Postoperative 30-day Complication by Nutritional Profile Group

Postoperative 30-day Complications	Underweight Short N=656	Overweight Short N=733	Underweight Tall N=252	Overweight Tall N=1,534	Normal N=26,862	*P Value
Surgical Site Infection	13 (2.0)	34 (4.6)	6 (2.4)	41 (2.7)	913 (3.4)	0.31
Postoperative Sepsis	16 (2.4)	6 (0.8)	1 (0.4)	26 (1.7)	224 (0.8)	0.0002
Return to Operating Room	32 (4.9)	39 (5.3)	5 (2.0)	64 (4.2)	769 (2.9)	<0.0001
Dehiscence	4 (0.6)	6 (0.8)	3 (1.2)	10 (0.7)	111 (0.4)	0.03
Transfusion within 72 hours	16 (2.4)	7 (1.0)	3 (1.2)	19 (1.2)	162 (0.6)	<0.0001
Reintubation	16 (2.4)	5 (0.7)	3 (1.2)	7 (0.5)	106 (0.4)	<0.0001
Acute Renal Failure	2 (0.3)	2 (0.3)	0 (0)	3 (0.2)	34 (0.1)	0.18
Central Line Associated Infection	3 (0.5)	1 (0.1)	0	6 (0.4)	51 (0.2)	0.24
Pneumonia	8 (1.2)	7 (1.0)	2 (0.8)	7 (0.5)	135 (0.5)	0.01
Cardiac Arrest	3 (0.5)	1 (0.1)	1 (0.4)	5 (0.3)	35 (0.1)	0.02
Deep Vein Thrombosis	1 (0.2)	1 (0.1)	1 (0.4)	4 (0.3)	56 (0.2)	0.82
Urinary Tract Infections	4 (0.6)	5 (0.7)	0 (0)	11 (0.7)	155 (0.6)	0.84
Mortality	4 (0.6)	3 (0.4)	1 (0.4)	5 (0.3)	51 (0.2)	0.005
Composite 30-day Morbidity	66 (10.1)	61 (8.3)	20 (7.9)	107 (7.0)	1,634 (6.1)	<0.0001
Healthcare associated Infections	34 (5.2)	46 (6.3)	9 (3.6)	79 (5.2)	1,287 (4.8)	0.18
Re-intervention events	48 (7.3)	43 (5.9)	8 (3.2)	71 (4.6)	881 (3.3)	<0.0001

*Derived from a chi-square test comparing complications among nutritional profile group

Table 3: Multivariate Logistic Regression Predicting Composite 30-day Morbidity

	Odds Ratio*	95% Confidence Interval*	P value*
Composite Morbidity CPT Linear Risk	0.38	0.36-0.40	<0.0001
Age	0.99	0.98-1.00	0.07
ASA Class	1.02	1.00-1.04	0.06
Underweight Short	1.35	1.03-1.75	0.04
Overweight Short	1.43	1.06-1.89	0.01
Underweight Tall	1.32	0.81-2.22	0.30
Overweight Tall	1.00	0.81-1.25	0.97

Both composite 30-day morbidity CPT linear risk and age were continuous variables. *Derived from Proc Mianalyze following multiple imputation of the four nutritional profile groups using Proc Glimmix.

Table 4: Multivariate Logistic Regression Predicting Composite Healthcare associated Infections

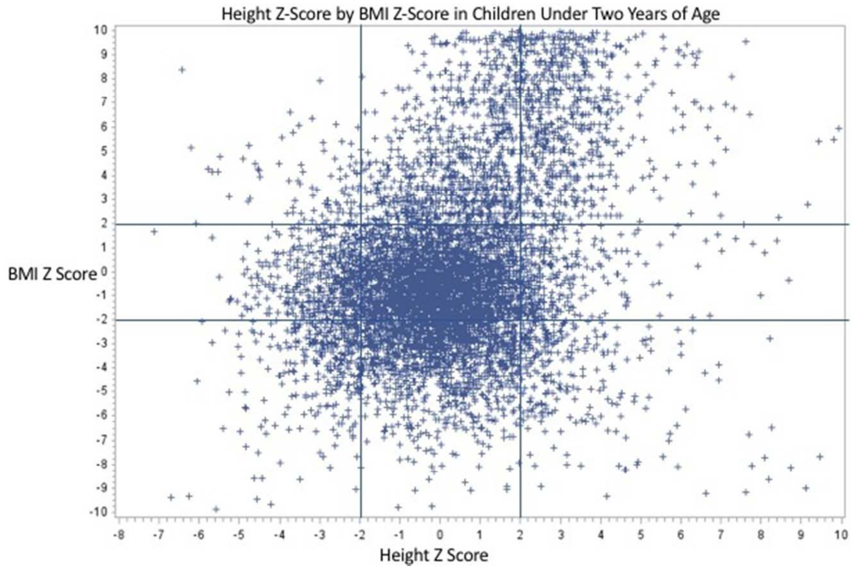
	Odds Ratio*	95% Confidence Interval*	P value*
Composite HAI CPT Linear Risk	0.33	0.30-0.36	<0.0001
Age	0.98	0.97-0.99	0.0001
ASA Class	1.05	1.02-1.08	<0.0001
Underweight Short	0.89	0.60-1.33	0.56
Overweight Short	1.43	1.05-1.92	0.02
Underweight Tall	0.75	0.37-1.52	0.42
Overweight Tall	1.15	0.90-1.45	0.27

Both composite healthcare associated infection CPT linear risk and age were continuous variables. *Derived from Proc Mianalyze following multiple imputation of the four nutritional profile groups using Proc Glimmix.

Table 5: Multivariate Logistic Regression Predicting Composite Re-intervention Events

	Odds Ratio*	95% Confidence Interval*	P value*
Composite RIE CPT Linear Risk	0.34	0.31-0.36	<0.0001
Age	0.99	0.98-1.00	0.28
ASA Class	1.01	0.98-1.01	0.35
Underweight Short	1.75	1.28-2.38	0.001
Overweight Short	1.79	1.30-2.50	0.001
Underweight Tall	0.99	0.47-2.08	0.97
Overweight Tall	1.08	0.82-1.41	0.58

Both composite re-intervention events CPT linear risk and age were continuous variables. *Derived from Proc Mianalyze following multiple imputation of the four nutritional profile groups using Proc Glimmix.



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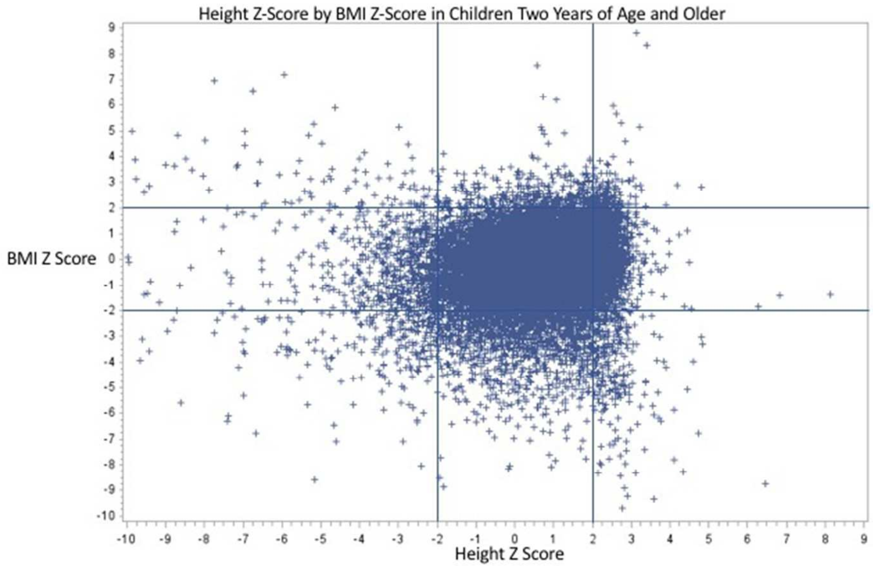

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Supplemental File 1: Major abdominal cases accrued in ACS-NSQIP-P

CPT	PROCEDURE DESCRIPTION
22900	Abdominal Wall Tumor Excision
37181-38120	Splenic Procedures
38562-38780	Lymphadenectomy
39502	Paraesophageal Hernia Repair
43280-43326	Fundoplication
43520-43840	Gastric Procedures
44005	Lysis of Adhesions
44010-44025	Enterotomy
44050	Reduction of Volvulus, Intussusception or Internal Hernia
44055	Ladd Procedure
44110-46748	Bowel Resection and Ostomy
47100-47130	Liver Resection
47480-47620	Cholecystectomy
47700-47800	Biliary Procedures
48120-48146	Pancreatic Resection
35840, 49000-49322	Abdominal Exploration)
49324-49421	Peritoneal Dialysis Catheter Placement
49600-49611	Omphalocele Repair
50205	Renal Biopsy
50220-50548	Nephrectomy
51500	Urachal Cyst Excision
51530-51585	Cystostomy and Cystectomy
57106-57112	Vaginectomy

Supplemental File 2: Auxiliary independent preoperative patient and procedure variables used in the multiple imputation model

Procedure case mix CPT code linear risk variable
Inpatient Status
Case Status
Elective
Urgent
Emergent
Male Gender
Hispanic
Age
Age 29 days – 364 days
Age 1 – 2 years
Age 3 – 5 years
Age 6 – 7 years
Age 8 – 12 years
Age 13 – 18 years
Premature birth
Metabolic & Nutritional Conditions
Parenteral and enteral nutritional Support
Greater than 10% weight loss within 6 months
Nutritional Profile Groups
Underweight Short
Overweight Short
Underweight Tall
Overweight Tall
Normal
Renal Conditions
Acute Renal failure
American Society of Anesthesiologists Class
ASA I
ASA II
ASA III
ASA IV
ASA V
Gastrointestinal Conditions
Esophageal Gastrointestinal Disease
Hepatobiliary Disease
Cardiovascular Conditions
Cardiac Surgery
Neurologic Conditions
Cerebrovascular Accident
Seizure Disorder
Cerebral Palsy
Neuromuscular Disorder

Developmental delay
CNS Structural Abnormality
Hematologic & Immunologic Conditions
Bleeding Disorder
Steroid use within 30 days
Immune Disease
Hematologic Disorder
Bone Marrow Transplant
Transplantation
Preoperative Red Blood Cell Transfusion
Pulmonary Conditions
Asthma
Chronic Lung Disease
Cystic Fibrosis
Structural Pulmonary Abnormality
Oxygen supplementation
Tracheostomy
Acuity of Condition
Prior surgery within 30 days
Open Wound
Cardiopulmonary Resuscitation
Do Not Resuscitate
Inotropic Support
Preoperative Sepsis within 48 hours
No sepsis
Systemic Inflammatory Response Syndrome
Sepsis
Septic shock

These variables were included in hierarchical Multiple imputation model.