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Research Article

Keywords: Appendicitis, Obesity, Ultrasound, Computed tomography, Pediatric surgery, Appendectomy

Posted Date: November 12th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10853108/v1

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Additional Declarations: No competing interests reported.

Impact of Body Mass Index Percentile on Ultrasound Diagnostic Performance and Operative Duration in Pediatric Appendicitis

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Abstract

Purpose: Childhood obesity may affect diagnostic imaging and operative duration in pediatric appendicitis. We evaluated associations between body mass index (BMI) percentile, imaging outcomes, and operative duration.

Methods: We performed a retrospective cohort study of children younger than 18 years with surgically confirmed appendicitis presenting to a tertiary pediatric emergency department from 2010–2023. BMI percentiles were categorized using Centers for Disease Control and Prevention standards. Outcomes included computed tomography (CT) utilization, nondiagnostic ultrasound, and operative duration. Multivariable models adjusted for age, sex, and calendar year.

Results: Of 2,275 children, 2,011 had valid BMI classification. CT utilization did not differ across BMI categories (p=0.143). Nondiagnostic ultrasound was more frequent in children with Overweight and Obesity, although categorical differences were not significant (p=0.079). Increasing BMI percentile was independently associated with nondiagnostic ultrasound (aOR 1.07 per 10-percentile increase, 95% CI 1.02–1.13; p=0.011) and longer operative duration (β=0.69 minutes per 10-percentile increase, 95% CI 0.07–1.32; p=0.030), but not CT utilization (p=0.146).

Conclusion: Increasing BMI percentile was associated with nondiagnostic ultrasound and modestly longer operative duration, but not CT utilization.

Keywords: Appendicitis; Obesity; Ultrasound; Computed tomography; Pediatric surgery; Appendectomy

Introduction

Acute appendicitis remains one of the most common surgical emergencies in children and a leading indication for urgent abdominal operation worldwide [1,2]. In the United States, pediatric appendicitis accounts for substantial emergency department utilization and operative volume, with peak incidence occurring during adolescence [2,3]. Although diagnostic and treatment pathways have evolved, appendicitis continues to carry meaningful clinical and resource implications, particularly when diagnosis is delayed [4].

At the same time, childhood obesity has become increasingly prevalent. Contemporary guidelines and epidemiologic studies demonstrate a marked rise in pediatric obesity over recent decades, with approximately one in five children and adolescents in the United States meeting criteria for obesity [5,6]. Forecasting data suggest that overweight and obesity will continue to affect a growing proportion of children in coming decades [7]. As a result, pediatric surgeons and emergency physicians are increasingly caring for children with elevated body mass index (BMI) who present with acute surgical conditions, including appendicitis.

Current diagnostic algorithms for suspected pediatric appendicitis emphasize radiation-sparing imaging. Ultrasound is widely recommended as the first-line imaging modality because it avoids ionizing radiation and can provide high diagnostic accuracy when a definitive interpretation is obtained [8-11]. However, ultrasound performance is dependent on patient factors, operator experience, and appendix visualization. Nondiagnostic or equivocal ultrasound examinations frequently prompt additional imaging, most often computed tomography (CT), which may increase cost, emergency department length of stay, and radiation exposure [12,13].

Obesity may challenge the ultrasound-first paradigm. Prior studies have shown that increasing BMI is associated with lower rates of appendix visualization and higher rates of inaccurate, equivocal, or nondiagnostic ultrasound examinations in children with suspected appendicitis [14-17]. In addition, children with elevated BMI may receive higher radiation doses when CT is performed, creating a potential compounding risk when nondiagnostic ultrasound leads to CT escalation [18,19]. Despite these concerns, the relationship between BMI percentile, imaging escalation, and downstream operative outcomes remains incompletely characterized.

The impact of BMI on operative outcomes after pediatric appendectomy is also mixed. Large database studies have reported longer operative times and increased postoperative complications among children with elevated BMI, while other studies have found no significant association between obesity and resource utilization or morbidity when standardized pathways are used [20-23]. Furthermore, some evidence suggests that underweight children may also be vulnerable to adverse diagnostic or postoperative outcomes [24].

Given the rising prevalence of childhood obesity and the continued reliance on ultrasound-first pathways, further study is needed to clarify how BMI affects appendicitis evaluation and treatment. The purpose of this study was to evaluate the association between BMI percentile and diagnostic imaging outcomes, including CT utilization

and nondiagnostic ultrasound, as well as operative outcomes among children undergoing appendectomy. We hypothesized that increasing BMI percentile would be associated with reduced ultrasound diagnostic performance and longer operative duration.

Materials/Subjects and Methods

Study Design and Setting

We conducted a retrospective cohort study of pediatric patients presenting to a large urban tertiary pediatric emergency department with surgically confirmed appendicitis between January 1, 2010, and December 31, 2023. The institution is staffed by pediatric surgeons, pediatric emergency medicine physicians, and emergency medicine physicians and serves as a training center for residents and fellows. The study was approved by the Institutional Review Board at Corewell Health (IRB No. 2024-128), with a waiver of informed consent due to the retrospective study design.

Patients were identified using a structured query of the Epic Clarity electronic health record database (Epic Systems Corporation, Madison, WI), accessed through the institution's analytical reporting platform. Consistent with prior institutional methodology, patients were identified using International Classification of Diseases, Ninth and Tenth Revision (ICD-9/10) diagnosis codes and Current Procedural Terminology (CPT) codes for appendectomy. To capture initial presentations only, analyses were restricted to the first emergency department encounter per unique medical record number.

A total of 2,275 unique pediatric patients with surgically confirmed appendicitis were identified during the study period. Patients without sufficient anthropometric data to calculate body mass index (BMI) percentile were excluded. The final analytic cohort consisted of 2,011 patients with valid BMI classification.

Exposure and Outcome Measures

The primary exposure was BMI percentile. BMI was calculated using height and weight measurements obtained during the index hospitalization and converted to age- and sex-adjusted BMI percentiles using Centers for Disease Control and Prevention (CDC) growth standards. For descriptive analyses, patients were categorized as

Underweight (<5th percentile), Healthy weight (5th to <85th percentile), Overweight (85th to <95th percentile), and Obesity (≥95th percentile). Because BMI percentile represents a continuous measure of adiposity in children, primary multivariable analyses modeled BMI percentile as a continuous variable.

Primary imaging outcomes included CT utilization, ultrasound-to-CT escalation, and nondiagnostic ultrasound examinations. Ultrasound-to-CT escalation was defined as performance of a CT scan following an initial ultrasound examination during the same episode of care. Ultrasound examinations were classified as nondiagnostic according to the final radiology interpretation documented in the electronic medical record.

Operative outcomes included operative duration and hospital readmission. Operative duration was calculated using documented operating room start and stop times and reported in minutes. Operative duration analyses were restricted to patients with complete operative records.

Covariates

Demographic and clinical variables included age, sex, race, ethnicity, and admission status. Race was categorized as White, Black, Asian, Other/Unknown, and ethnicity was categorized as Hispanic or non-Hispanic. Calendar year was included in multivariable analyses to account for temporal changes in imaging utilization and operative practice patterns over the study period.

Statistical Analysis

Descriptive statistics were used to summarize patient characteristics. Continuous variables were assessed for normality and are reported as median with interquartile range (IQR) due to non-normal distributions. Comparisons among BMI categories were performed using the Kruskal-Wallis test for continuous variables and chi-square tests for categorical variables.

Multivariable logistic regression models were constructed to evaluate associations between BMI percentile and imaging outcomes, including CT utilization and nondiagnostic ultrasound. Results are reported as adjusted odds ratios (aORs) with 95% confidence intervals (CIs). Multivariable linear regression was performed to evaluate the

association between BMI percentile and operative duration, with regression coefficients reported alongside corresponding 95% confidence intervals.

Covariates were selected a priori based on clinical relevance and prior literature. All multivariable models were adjusted for age, sex, and calendar year. BMI percentile was modeled as a continuous variable and reported per 10-percentile increase to improve clinical interpretability. All statistical tests were two-sided, with $p < 0.05$ considered statistically significant.

Analyses were conducted using SAS version 9.4 (SAS Institute, Inc., Cary, NC). Reporting follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Results

A total of 2,275 children with surgically confirmed appendicitis were identified during the study period. After exclusion of patients without sufficient anthropometric data for BMI percentile calculation, the final analytic cohort included 2,011 patients. Patients were categorized as Underweight (n=120, 6.0%), Healthy weight (n=1,198, 59.6%), Overweight (n=305, 15.2%), or Obesity (n=388, 19.3%) (Table 1).

Table 1. Baseline Characteristics of Children Undergoing Appendectomy by CDC BMI Category.

Characteristic	Underweight (<5th %ile) n=120	Healthy Weight (5th–<85th %ile) n=1198	Overweight (85th–<95th %ile) n=305	Obesity (≥95th %ile) n=388	p-value
Age, years, median (IQR)	10.0 (7.1–13.0)	12.1 (9.2–14.6)	12.9 (10.0–15.1)	11.7 (9.0–14.3)	<0.001
BMI, kg/m², median (IQR)	13.5 (12.9–14.7)	17.7 (16.1–19.9)	23.6 (20.7–25.4)	27.7 (24.2–31.4)	<0.001
BMI percentile, median (IQR)	0.8 (0.2–2.6)	50.0 (27.7–69.9)	90.6 (88.0–92.8)	98.2 (96.8–99.0)	<0.001
Male sex, n (%)	74 (61.7%)	692 (57.8%)	168 (55.1%)	268 (69.1%)	<0.001
Observation status, n (%)	29 (24.2%)	301 (25.1%)	70 (23.0%)	98 (25.3%)	0.703
Race, n (%)					0.394
White	82 (68.3%)	865 (72.2%)	216 (70.8%)	259 (66.8%)	
Black	10 (8.3%)	117 (9.8%)	39 (12.8%)	52 (13.4%)	
Asian	8 (6.7%)	43 (3.6%)	11 (3.6%)	12 (3.1%)	
Other	18 (15.0%)	161 (13.4%)	36 (11.8%)	61 (15.7%)	
Unknown	2 (1.7%)	12 (1.0%)	3 (1.0%)	4 (1.0%)	

Characteristic	Underweight (<5th %ile) n=120	Healthy Weight (5th–<85th %ile) n=1198	Overweight (85th–<95th %ile) n=305	Obesity (≥95th %ile) n=388	p-value
Hispanic ethnicity, n (%)	5 (4.2%)	55 (4.6%)	14 (4.6%)	29 (7.5%)	0.117

Footnote: BMI categories were defined according to CDC BMI-for-age percentiles. Continuous variables are presented as median (IQR). Categorical variables are presented as n (%). P-values were calculated using Kruskal–Wallis tests for continuous variables and χ^2 tests for categorical variables.

Patient Characteristics

Increasing BMI category was associated with significant differences in age, BMI, BMI percentile, and sex distribution (all p<0.001). Median age ranged from 10.0 years (IQR 7.1–13.0) among underweight children to 12.9 years (IQR 10.0–15.1) among overweight children. Male patients comprised a greater proportion of the Obesity category compared with other BMI categories (69.1% vs 55.1%–61.7%, p<0.001). Race, ethnicity, and observation status did not differ significantly across BMI categories (Table 1).

Diagnostic Imaging Outcomes

CT utilization increased numerically across BMI categories, from 30.0% among underweight children to 34.8% among children in the Obesity category, although this difference was not statistically significant (p=0.143). Ultrasound-to-CT escalation similarly increased from 31.7% to 45.5% across BMI categories but did not reach statistical significance (p=0.080). Nondiagnostic ultrasound examinations occurred more frequently among children in the Overweight and Obesity categories (36.2% and 38.0%, respectively) than among underweight and healthy-weight children (24.4% and 27.7%, respectively), approaching statistical significance (p=0.079). Emergency department length of stay did not differ significantly among BMI categories (p=0.726) (Table 2).

Table 2. Key Diagnostic Imaging Outcomes

Outcome	Underweight	Healthy Weight	Overweight	Obesity	p-value
Any CT utilization, n (%)	36 (30.0)	348 (29.0)	101 (33.1)	135 (34.8)	0.143
US→CT escalation among US-first patients, n (%)	13 (31.7)	140 (32.2)	43 (37.4)	45 (45.5)	0.080

Outcome	Underweight	Healthy Weight	Overweight	Obesity	p-value
Nondiagnostic ultrasound among US patients, n (%)	10 (24.4)	121 (27.7)	42 (36.2)	38 (38.0)	0.079
ED length of stay, hours, median (IQR)	5.7 (3.7–7.5)	5.6 (4.0–7.8)	5.9 (4.1–8.0)	5.7 (3.9–8.1)	0.726

Footnote: US = ultrasound; CT = computed tomography; ED = emergency department. US→CT escalation was defined as CT obtained following an initial ultrasound examination. Percentages for US→CT escalation and nondiagnostic ultrasound were calculated among patients who underwent ultrasound.

Association Between BMI Percentile and Imaging Outcomes

After adjustment for age, sex, and calendar year, BMI percentile was not independently associated with CT utilization (aOR 1.02 per 10-percentile increase, 95% CI 0.99–1.05, p=0.146). Increasing age was associated with greater CT utilization (aOR 1.09 per year, 95% CI 1.06–1.12, p<0.001), whereas male sex was associated with lower odds of CT utilization (aOR 0.80, 95% CI 0.66–0.98, p=0.028). CT utilization decreased over the study period (aOR 0.90 per year, 95% CI 0.88–0.93, p<0.001) (Table 3).

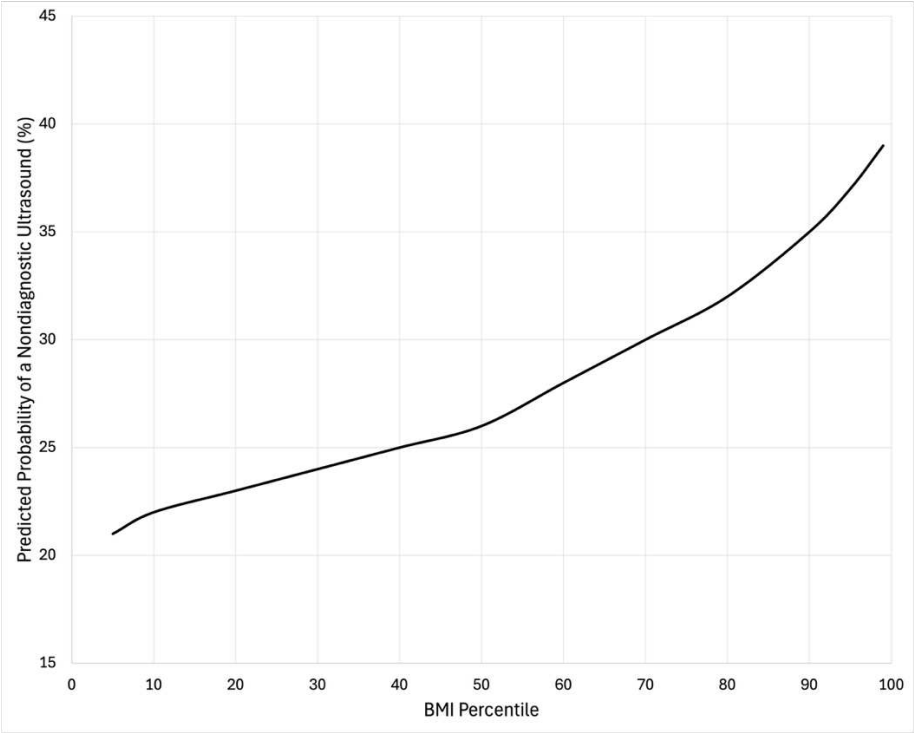
Table 3. Multivariable Association Between BMI Percentile and Imaging Outcomes

Predictor	CT Utilization aOR (95% CI)	P-value	Nondiagnostic Ultrasound aOR (95% CI)	p-value
BMI percentile (per 10-point increase)	1.02 (0.99–1.05)	0.146	1.07 (1.02–1.13)	0.011
Age, per year	1.09 (1.06–1.12)	<0.001	1.02 (0.97–1.06)	0.429
Male sex	0.80 (0.66–0.98)	0.028	0.76 (0.55–1.07)	0.118
Calendar year	0.90 (0.88–0.93)	<0.001	1.01 (0.96–1.06)	0.731

Footnote: aOR = adjusted odds ratio; CI = confidence interval. Multivariable logistic regression models were adjusted for age, sex, and calendar year. BMI percentile was modeled as a continuous variable and reported per 10-percentile increase.

In contrast, increasing BMI percentile was independently associated with nondiagnostic ultrasound examinations. For every 10-percentile increase in BMI percentile, the odds of a nondiagnostic ultrasound increased by 7% (aOR 1.07, 95% CI 1.02–1.13, p=0.011). The predicted probability of a nondiagnostic ultrasound increased progressively across the BMI percentile spectrum (Table 3, Figure 1).

Figure 1. Predicted probability of nondiagnostic ultrasound by BMI percentile.



Operative Outcomes

Operative duration data were available for 1,005 patients with complete operative records. Median operative duration increased progressively across BMI categories, from 35.0 minutes (IQR 29.5–48.5) among underweight children to 51.0 minutes (IQR 39.0–64.0) among children in the Obesity category ($p<0.001$). Readmission rates ranged from 6.2% to 10.3% and did not differ significantly among BMI categories ($p=0.091$) (Table 4).

Table 4. Operative Duration and Readmission by BMI Category and Multivariable Analysis

Outcome / Predictor	Estimate	95% CI	p-value
Operative Outcomes			
Operative duration, min, median (IQR)			<0.001
Underweight	35.0 (29.5–48.5)	—	—
Healthy Weight	44.0 (33.0–60.0)	—	—
Overweight	45.0 (34.0–61.0)	—	—
Obesity	51.0 (39.0–64.0)	—	—
Readmission, n (%)			0.091

Outcome / Predictor	Estimate	95% CI	p-value
Underweight	10 (8.3%)	—	—
Healthy Weight	80 (6.7%)	—	—
Overweight	19 (6.2%)	—	—
Obesity	40 (10.3%)	—	—
Multivariable Linear Regression for Operative Duration			
BMI percentile (per 10-point increase)	0.69 min	0.07–1.32	0.030
Age, per year	0.13 min	−0.43–0.69	0.649
Male sex	1.05 min	−2.40–4.51	0.551
Calendar year (per 1-year increase)	1.34 min	0.66–2.02	<0.001

Footnote: CI = confidence interval. Linear regression coefficients represent the change in operative duration (minutes). Operative duration data were available for 1,005 patients with complete operative records and valid CDC BMI classification. BMI percentile was modeled continuously and reported per 10-percentile increase. Multivariable linear regression models were adjusted for age, sex, and calendar year. Calendar year was included to account for temporal changes in operative practice over the study period and represents the overall association between later study year and operative duration, independent of BMI percentile. Readmission rates were calculated from the full BMI-classified cohort; operative duration analyses were limited to the 1,005 patients with complete operative time data.

Multivariable linear regression demonstrated that increasing BMI percentile was independently associated with longer operative duration. Each 10-percentile increase in BMI percentile was associated with a 0.69-minute increase in operative time (95% CI 0.07–1.32, p=0.030). Calendar year was also associated with operative duration (β=1.34 minutes per year, 95% CI 0.66–2.02, p<0.001), whereas age and sex were not significant predictors (Table 4).

Discussion

In this retrospective cohort study of 2,011 children undergoing appendectomy, increasing BMI percentile was independently associated with higher odds of nondiagnostic ultrasound and longer operative duration. In contrast, BMI percentile was not independently associated with overall CT utilization after adjustment for age, sex, and calendar year. These findings suggest that elevated BMI primarily affects ultrasound diagnostic performance and operative duration rather than directly increasing CT utilization.

Our finding that increasing BMI percentile was associated with nondiagnostic ultrasound is consistent with prior studies demonstrating reduced ultrasound performance in children with elevated BMI. Tantisook et al. found that children in the Obesity category had significantly higher odds of inaccurate or equivocal ultrasound examinations, while Pfeifer et al. demonstrated a dose-response relationship between increasing BMI z-score and decreased appendix visualization [14,15]. Schuh et al. and Keller et al. similarly identified elevated BMI as an important predictor of nondiagnostic ultrasound in children with suspected appendicitis [16,17]. The present study extends this literature by modeling BMI percentile continuously and demonstrating an independent association between increasing BMI percentile and nondiagnostic ultrasound after adjustment for relevant clinical factors.

Although nondiagnostic ultrasound increased with BMI percentile, BMI percentile was not independently associated with CT utilization. This distinction is important. Prior studies have shown that indeterminate ultrasound examinations are associated with subsequent CT use [12,13]. However, CT utilization is influenced not only by ultrasound findings, but also by clinical examination, laboratory results, surgical consultation, institutional pathways, availability of advanced imaging, and provider preference. Our results suggest that while increasing BMI may reduce the diagnostic yield of ultrasound, contemporary clinical pathways may mitigate direct escalation to CT. These findings support continued use of ultrasound-first pathways in children across the BMI spectrum while recognizing that clinicians should anticipate a higher likelihood of nondiagnostic examinations among patients with elevated BMI percentile.

The radiation implications remain important. Children in the Obesity category may receive higher radiation doses during abdomen and pelvis CT compared with normal-weight peers, and higher BMI has been associated with increased effective dose [18,19]. Therefore, even if CT utilization is not independently increased by BMI in the present cohort, children with elevated BMI who do require CT may still be exposed to greater radiation burden. This supports continued efforts to optimize ultrasound quality, use structured clinical pathways, and consider radiation-sparing second-line imaging strategies when ultrasound is nondiagnostic.

Operative duration also increased with BMI percentile. Children in the Obesity category had the longest median operative duration, and BMI percentile remained independently associated with operative time in multivariable analysis. These findings align with prior reports that elevated BMI is associated with longer operative

times in pediatric appendectomy and other gastrointestinal operations [20-22]. Several technical factors may contribute to this association. Additional adipose tissue may require deeper dissection to reach the fascia, increase abdominal wall thickness at trocar sites, and prolong fascial and layered closure, all of which may contribute to longer operative duration even when the appendectomy itself is not substantially more complex.

Despite longer operative duration, readmission did not differ significantly by BMI category. This finding is consistent with studies suggesting that elevated BMI may increase technical complexity without necessarily worsening short-term postoperative outcomes [22,23]. The clinical significance of a modest increase in operative duration should therefore be interpreted carefully. Longer operative time may reflect increased technical difficulty and resource utilization, but it does not necessarily imply increased morbidity in all settings. The observed increase in operative duration may also have implications for resource utilization and cost. Longer operative duration during pediatric appendectomy has previously been associated with increased total hospital and operating room costs [25]. Although costs and reimbursement were not evaluated in the present study, these findings suggest that the potential economic implications of increased operative complexity among children with elevated BMI warrant further investigation. Institutional experience with laparoscopic appendectomy and standardized perioperative pathways may reduce the downstream impact of elevated BMI on postoperative recovery.

A strength of this study is the use of BMI percentile as both a categorical and continuous variable. Pediatric BMI interpretation requires age- and sex-adjusted percentiles, and categorical BMI groups are useful for clinical description. However, continuous modeling may better detect dose-response relationships across the BMI spectrum. In this study, unadjusted categorical comparisons did not reach statistical significance for nondiagnostic ultrasound, whereas adjusted continuous modeling demonstrated a significant association. This suggests that BMI may influence ultrasound performance across a continuum rather than only above a single BMI percentile threshold.

Limitations

This study has limitations. Its retrospective, single-institution design introduces the possibility of selection bias, missing data, and residual confounding. Imaging decisions were not randomized and may have been influenced by clinical examination, laboratory results, surgeon preference, radiologist availability, or institutional protocols that were not fully captured. Nondiagnostic ultrasound classification depended on radiology documentation and may be

subject to variation in reporting. Operative duration data were available only for patients with complete operative records and valid CDC BMI classification, which may introduce ascertainment bias. Additionally, BMI percentile does not directly measure body composition or fat distribution, both of which may influence imaging and operative difficulty.

Conclusion

Increasing BMI percentile was independently associated with nondiagnostic ultrasound examinations and longer operative duration among children with appendicitis. In contrast, BMI percentile was not independently associated with CT utilization after adjustment for age, sex, and calendar year. These findings suggest that elevated BMI may reduce the diagnostic performance of ultrasound-first imaging pathways and modestly increase operative duration without substantially affecting downstream imaging utilization. As childhood obesity continues to rise, strategies to improve diagnostic accuracy and optimize appendicitis care in children with elevated BMI warrant further investigation.

Acknowledgements: The authors thank the Department of Pediatric Surgery and the Department of Pediatric Emergency Medicine at Corewell Health William Beaumont University Hospital for their support of this study.

Declarations

Funding: No funds, grants, or other support were received for conducting this study.

Competing Interests: The authors have no relevant financial or non-financial interests to disclose.

Ethics Approval: This retrospective study was approved by the Institutional Review Board at Corewell Health (IRB No. 2024-128) and was conducted in accordance with the ethical standards of the institutional research committee and the Declaration of Helsinki and its later amendments.

Consent to Participate: The requirement for informed consent was waived by the Institutional Review Board because of the retrospective nature of the study.

Consent for Publication: Not applicable.

Data Availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Figure Legend:

Figure 1. Predicted probability of nondiagnostic ultrasound by BMI percentile. Predicted probability of a nondiagnostic ultrasound examination across the BMI percentile spectrum derived from the adjusted multivariable logistic regression model. Increasing BMI percentile was independently associated with higher odds of a nondiagnostic ultrasound examination (aOR 1.07 per 10-percentile increase, 95% CI 1.02–1.13; p=0.011). Shaded bands represent 95% confidence intervals.

Table Legend:

Table 1. Baseline Characteristics of Children Undergoing Appendectomy by CDC BMI Category. Demographic and clinical characteristics stratified by CDC BMI-for-age percentile category. Continuous variables are presented as median (IQR) and categorical variables as n (%). Comparisons were performed using Kruskal-Wallis tests for continuous variables and χ^2 tests for categorical variables.

Table 2. Diagnostic Imaging Outcomes by CDC BMI Category. Imaging utilization and emergency department outcomes stratified by BMI category. US→CT escalation was defined as CT obtained following an initial ultrasound examination during the same encounter. Percentages for US→CT escalation and nondiagnostic ultrasound were calculated among patients who underwent ultrasound.

Table 3. Multivariable Association Between BMI Percentile and Imaging Outcomes. Adjusted logistic regression models evaluating associations between BMI percentile and imaging outcomes. BMI percentile was modeled continuously and reported per 10-percentile increase. Models were adjusted for age, sex, and calendar year.

Table 4. Operative Duration and Readmission by BMI Category and Multivariable Analysis. Operative outcomes stratified by CDC BMI category and multivariable linear regression evaluating factors associated with

362 operative duration. Operative duration analyses were limited to patients with complete operative records (n=1,005).

363 Regression coefficients represent the change in operative duration (minutes).