



Imaging utilization affects negative appendectomy rates in appendicitis: An ACS-NSQIP study

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ABSTRACT

Background: Negative appendectomy rates (NAR) historically ranged from 15 to 25%, but have decreased recently.

Methods: Using the 2016 ACS-NSQIP database, we identified patients who underwent appendectomies for appendicitis. Patients with and without appendicitis on pathology were compared. Multivariate analysis was used to identify predictors of negative appendectomies.

Results: 11,841 patients underwent appendectomies, with a NAR of 4.5%. Utilization rates of US, CT and MRI were 14.9%, 86.1%, and 1.1%. NAR's of US, CT, and MRI were 9.7%, 2.5%, and 7.1%, and 19.2% for patients without imaging. An ultrasound consistent with appendicitis has a NAR of 4.8%; adding a CT decreases it to 0.6%. Predictors of NA include females, smoking, no imaging, and ultrasounds. Factors with lower odds of NA include leukocytosis, sepsis, and CTs.

Conclusions: The NAR in the 2016 ACS-NSQIP population is 4.5%. CTs are the most frequently used imaging modality and have the lowest NAR. Obtaining a CT in addition to an ultrasound is associated with lower NAR. This should be further explored with a cost-benefit analysis between multiple imaging studies versus negative appendectomies.

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Introduction

Acute appendicitis is one of the most common surgical emergencies, with an estimated lifetime risk of 7–8%.¹ Its diagnosis is based on a combination of history, physical exam, and laboratory testing, with or without the aid of imaging.^{2,3} The disease progresses from early, uncomplicated appendicitis to perforation and peritonitis, which are associated with significant morbidity.⁴ Prompt and accurate diagnosis with early intervention remain the cornerstone of treatment.⁵

Historically, the rate of negative appendectomies (NA) – pathologically normal appendices in patients who undergo surgery for suspected appendicitis – ranged from 15 to 25% in the US.^{4,6} These rates were widely accepted, as a low threshold to operate for suspected appendicitis could potentially decrease the rate of perforated appendicitis.^{7,8} However this has since been challenged.^{4,8,9} Studies show that negative appendectomies are associated with considerable cost, prolonged hospitalizations, and morbidity.^{7,10}

In recent times, surgeons have access to highly sensitive and specific imaging studies, such as ultrasound (US), CT, and MRI.¹¹ While overall negative appendectomy rates (NAR) in the nation have decreased, studies regarding the effects of imaging studies on NAR's are mixed; those that address the utility of multiple imaging modalities are generally limited to small single-center studies.^{9,10,12–15}

In this study, we analyzed the American College of Surgeons National Surgical Quality Improvement Project (ACS-NSQIP) database to assess current utilization rates of imaging in appendicitis. We assessed each imaging modality's effect on the negative appendectomy rate and the incremental value of additional imaging. Finally, we identified predictors of negative appendectomies.

Methods

ACS-NSQIP is a national database of clinical information collected from participating hospitals across the nation. It contains blinded, risk-adjusted data regarding complication rates and surgical outcomes, and compares hospital's performance with a national benchmark. The data are collected by trained surgical clinical reviewers by chart review, and are coded into variables with strict, rigorous definitions to minimize inter-rater variability. The data are then de-identified for public use.

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The 2016 ACS-NSQIP Procedure-Targeted Appendectomy database was used to identify patients who underwent appendectomies alone based on CPT codes 44950, 44960, and 44970. Patients were divided into two cohorts – positive and negative appendectomies – for comparison. Variables including patient demographics, comorbidities, preoperative labs, imaging study results, pathology reports, hospital course, and postoperative outcomes were obtained. Imaging results were classified as “consistent”, “not consistent”, and “indeterminate” as defined by the ACS-NSQIP database. Leukocytosis was defined as a white blood cell count greater than 11,000 per mm.³ The presence of SIRS or sepsis was defined by the ACS-NSQIP variable for “Systemic Sepsis”, which categorizes patients as having SIRS, sepsis, or none.

Statistical analysis

Normally distributed continuous variables were described as mean ± standard deviation. Categorical variables were listed in absolute numbers and percent prevalence (%) in the study group. Statistical analyses were performed between positive and negative

appendectomies using IBM SPSS, Version 22.0 (SPSS, Inc, Armonk, NY). Independent 2 sample t-tests were used to assess normally distributed continuous variables for significance, and a Mann-Whitney *U* test was used to assess non-normally distributed continuous and ordinal variables. Categorical variables were compared using a chi-squared test. After identifying variables that had a statistically significant difference on univariate analysis, a binary logistic regression model was used to identify independent predictors of negative appendectomies.

Results

A total of 11,841 patients underwent appendectomies for appendicitis in the 2016 ACS-NSQIP database (Table 1). 527 cases were negative appendectomies on pathology, resulting in an overall NAR of 4.5%. The average age was 39.6 ± 16.4 years, and 51.7% of patients were male. The two most common comorbidities were hypertension (15.6%) and diabetes (5.1%). The average length of hospital stay was 1.8 ± 4.0 days, and the average duration from hospital admission to surgery was 0.4 ± 5.9 days. The readmission rate was 3.3%, and the 30-day postoperative mortality rate was 0.1%.

Table 1
Characteristics of patients undergoing appendectomy.

| Characteristics | Total, n = 11841 | Appendicitis n = 11314 (95.5) | Negative Appendectomy n = 527 (4.5) | P Value |
|----------------------------------|------------------|-------------------------------|-------------------------------------|---------|
| Age | 39.57 ± 16.41 | 39.72 ± 16.45 | 36.17 ± 15.34 | <.001 |
| Sex | | | | <.001 |
| Male | 6117 (51.7) | 5932 (52.4) | 185 (35.1) | |
| Female | 5724 (48.3) | 5382 (47.6) | 342 (64.9) | |
| Race/Ethnicity | | | | .059 |
| White | 7377 (62.3) | 7048 (62.3) | 329 (62.4) | |
| Black or African American | 903 (7.6) | 866 (7.7) | 37 (7.0) | |
| Asian | 400 (3.4) | 394 (3.5) | 6 (1.1) | |
| American Indian/Alaskan | 144 (1.2) | 135 (1.2) | 9 (1.7) | |
| Hawaiian/Pacific Islander | 40 (0.3) | 39 (0.3) | 1 (0.2) | |
| Other | 2977 (25.1) | 2832 (25.0) | 145 (27.5) | |
| BMI | 28.48 ± 6.58 | 28.51 ± 6.58 | 27.79 ± 6.57 | .023 |
| Diabetes | 602 (5.1) | 569 (5.0) | 33 (6.3) | .453 |
| Smoker | 1967 (16.6) | 1838 (16.2) | 129 (24.5) | <.001 |
| History of severe COPD | 119 (1.0) | 113 (1.0) | 6 (1.1) | .753 |
| Hypertension | 1843 (15.6) | 1774 (15.7) | 69 (13.1) | .109 |
| Chronic steroid use | 188 (1.6) | 175 (1.5) | 13 (2.5) | .099 |
| Bleeding disorder | 204 (1.7) | 200 (1.8) | 4 (0.8) | .082 |
| Pre-op Systemic Sepsis | | | | <.001 |
| SIRS | 2422 (20.5) | 2356 (20.8) | 66 (12.5) | |
| Sepsis | 1354 (11.4) | 1341 (11.9) | 13 (2.5) | |
| Septic Shock | 32 (0.3) | 32 (0.3) | 0 | |
| Pre-operative BUN | 12.85 ± 6.45 | 12.87 ± 6.51 | 12.25 ± 5.15 | .041 |
| Pre-operative Creatinine | 0.89 ± 0.50 | 0.90 ± 0.51 | 0.82 ± 0.22 | <.001 |
| Pre-operative WBC | 12.76 ± 4.49 | 12.91 ± 4.44 | 9.45 ± 4.15 | <.001 |
| Total length of stay | 1.82 ± 3.98 | 1.82 ± 4.02 | 1.95 ± 3.17 | .457 |
| Days from admission to operation | 0.41 ± 5.73 | 0.40 ± 5.86 | 0.51 ± .97 | .673 |
| 30d Post-op Mortality | 15 (0.1) | 13 (0.1) | 2 (0.4) | .095 |
| Readmission | 385 (3.3) | 365 (3.2) | 20 (3.8) | .054 |
| US | 1760 (14.9) | 1613 (14.3) | 147 (27.9) | <.001 |
| Not Consistent ^a | 324 (17.9) | 279 (16.8) | 45 (30.0) | <.001 |
| Indeterminate | 542 (30.0) | 470 (28.4) | 72 (48.0) | |
| Consistent ^a | 940 (52.0) | 907 (54.8) | 33 (22.0) | |
| CT | 10195 (86.1) | 9895 (87.5) | 300 (56.9) | <.001 |
| Not Consistent ^a | 228 (2.2) | 142 (1.4) | 86 (28.3) | <.001 |
| Indeterminate | 319 (3.1) | 243 (2.4) | 76 (25.0) | |
| Consistent ^a | 9722 (94.7) | 9580 (96.1) | 142 (46.7) | |
| MRI | 125 (1.1) | 113 (1.0) | 12 (2.3) | .005 |
| Not Consistent ^a | 14 (9.3) | 11 (8.0) | 3 (21.4) | <.001 |
| Indeterminate | 39 (25.8) | 30 (21.9) | 9 (64.3) | |
| Consistent ^a | 98 (64.9) | 96 (70.1) | 2 (14.3) | |
| No Imaging | 719 (6.1) | 581 (5.1) | 138 (26.2) | <.001 |
| Single Imaging Study | 10173 (85.9) | 9853 (87.1) | 320 (60.7) | <.001 |
| US + CT | 866 (7.3) | 804 (7.1) | 62 (11.8) | <.001 |
| US + MRI | 62 (0.5) | 56 (0.5) | 6 (1.1) | <.001 |
| CT + MRI | 39 (0.3) | 36 (0.3) | 3 (0.6) | <.001 |
| US, CT and MRI | 9 (0.1) | 8 (0.1) | 1 (0.2) | <.001 |

^a With appendicitis.

When comparing patients with negative appendectomies to those with appendicitis, negative appendectomies were more likely to be female (64.9% vs 47.6%, $p < .001$) and more likely to have no imaging studies (26.2% vs 5.1%, $p < .001$). They were less likely to have signs of SIRS or sepsis (12.5% vs 20.8%, and 2.5% vs 11.9%, $p < .001$). The average white blood cell count for negative appendectomies was also lower (9.45 vs 12.91, $p < .001$). Negative appendectomies had higher rates of ultrasounds (27.9% vs 14.3%, $p < .001$) and lower rates of CT's (56.9% vs 87.5%, $p < .001$). Negative appendectomies were more likely to have an indeterminate imaging result (34.2% vs 6.4%, $p < .001$).

Imaging utilization rates

The majority of patients had one or more imaging studies performed (93.9%), while some proceeded to surgery without any imaging (6.1%). CT's, US's, and MRI's were obtained in 86.1%, 14.9%, and 1.1% of patients, respectively. Two imaging modalities were obtained in 8.1% of patients, while three imaging modalities were obtained in 0.1% of patients. Of those patients who received two imaging modalities, 88.7% had an US and CT. In this subgroup, 19.7% of these patients had an US that was consistent with appendicitis, but still received an additional CT (Table 2).

Negative appendectomy rates with imaging studies

Patients who proceeded to surgery without imaging had a NAR of 19.2%. In comparison, patients who proceeded to surgery with one or more imaging studies had a NAR of 3.5%. A single US, CT, or MRI had a NAR of 9.7%, 2.5%, and 7.1%, respectively. If the US, CT or MRI result was consistent with appendicitis, the NAR were lower at 4.8%, 1.3%, and 2.3%, respectively (Table 2). However, if the result was indeterminate or negative, the negative appendectomy rates were 32.9%, 26.7%, and 14.8%, respectively (data not shown).

866 patients had both an US and a CT (Table 3). If the patient had an ultrasound that was consistent with appendicitis, the NAR after obtaining an additional CT (regardless of the CT result) was 0.6%, compared to 4.8% for a consistent ultrasound alone. If the patient had an ultrasound that was indeterminate, the NAR after obtaining an additional CT was 8.1%, compared to 35.9% for an indeterminate ultrasound alone. If the patient had an ultrasound that was not consistent with appendicitis, the NAR after obtaining an additional CT was 10.5%, compared to 27.2% for non-consistent ultrasound alone.

Binary logistic regression analysis

Table 4 reports the results of the binary logistic regression analysis. Factors associated with higher odds of negative appendectomy include female gender, history of current smoking, no

Table 2
Imaging utilization and negative appendectomy rates with a single imaging study.

| | | Pathology | | NAR | Total NAR |
|----------------|----------------|-----------|----------|-------|-----------|
| | | Positive | Negative | | |
| US N = 904 | Consistent | 716 | 30 | 4.0% | 9.1% |
| | Indeterminate | 66 | 37 | 35.9% | |
| | Not Consistent | 40 | 15 | 27.2% | |
| CT N = 9308 | Consistent | 8756 | 122 | 1.4% | 2.5% |
| | Indeterminate | 197 | 51 | 20.6% | |
| | Not Consistent | 118 | 64 | 35.2% | |
| MRI N = 70 | Consistent | 42 | 1 | 2.3% | 7.1% |
| | Indeterminate | 14 | 3 | 17.6% | |
| | Not Consistent | 9 | 1 | 10% | |

Table 3
Imaging utilization and negative appendectomy rates with multiple imaging studies.

| US | CT | Pathology | | NAR | Total NAR |
|---------------------------|----------------|-----------|----------|-------|-----------|
| | | Positive | Negative | | |
| Consistent N = 162 | Consistent | 148 | 0 | 0% | 0.6% |
| | Indeterminate | 8 | 0 | 0% | |
| | Not Consistent | 5 | 1 | 16.7% | |
| Indeterminate N = 405 | Consistent | 345 | 10 | 2.8% | 8.1% |
| | Indeterminate | 24 | 18 | 42.9% | |
| | Not Consistent | 3 | 5 | 62.5% | |
| Not Consistent N = 257 | Consistent | 207 | 7 | 3.3% | 10.5% |
| | Indeterminate | 8 | 6 | 42.9% | |
| | Not Consistent | 15 | 14 | 48.3% | |

Missing data rate: n = 42 (4.8%).

imaging studies, and ultrasounds. Factors associated with lower odds of negative appendectomy include meeting criteria for SIRS or sepsis, leukocytosis, and having a CT scan performed.

In this analysis, female gender was a significant predictor of negative appendectomy (OR 2.00, 95% CI 1.64–2.44). Patient history of smoking was also a predictor of negative appendectomy (OR 2.10, 95% CI 1.68–2.62). Patients who had no imaging (OR 4.89, 95% CI 3.21–7.45) or had an ultrasound (OR 2.55, 95% CI 1.89–3.43) had higher odds of negative appendectomies as well.

Several factors were associated with lower odds of negative appendectomy. Patients with leukocytosis had 67% lower odds of having a negative appendectomy (OR 0.33, 95% CI 0.27–0.40). Patients meeting SIRS or sepsis criteria also had lower odds (OR 0.68, 95% CI 0.52–0.88). Patients who had a CT scan done, regardless of result, had 34% lower odds of negative appendectomy (OR 0.66, 95% CI 0.47–0.93).

The model fit the observed data well as tested using the C statistic (C = 0.79) and the Hosmer-Lemeshow test ($p = .199$). The C statistic represents the area under the receiver-operating curve (ROC). In the Hosmer-Lemeshow test, a P value greater than 0.05 signifies that the model fits the observed data.

Discussion

Historically, surgical dogma advised an aggressive approach towards suspected appendicitis to prevent disease progression

Table 4
Binomial logistic regression analysis for predictors of negative appendectomies.

| | Odds ratio | 95% CI | | P Value |
|-----------------------|------------|--------|-------|---------|
| | | Lower | Upper | |
| Gender | | | | |
| Male | Reference | | | |
| Female | 1.998 | 1.640 | 2.435 | <.001 |
| Smoking | | | | |
| No | Reference | | | |
| Yes | 2.099 | 1.683 | 2.616 | <.001 |
| SIRS or Sepsis | | | | |
| No | Reference | | | |
| Yes | .676 | .517 | .883 | .004 |
| Leukocytosis | | | | |
| No | Reference | | | |
| Yes | .327 | .265 | .404 | <.001 |
| CT | | | | |
| No | Reference | | | |
| Yes | .660 | .467 | .934 | .019 |
| US | | | | |
| No | Reference | | | |
| Yes | 2.547 | 1.891 | 3.429 | <.001 |
| Imaging Study | | | | |
| Yes | Reference | | | |
| No | 4.887 | 3.207 | 7.448 | <.001 |

from uncomplicated appendicitis to perforation and peritonitis.² As a result, negative appendectomy rates of 20% (and even as high as 40% in women) were acceptable and were considered the norm.⁶ This train of thought has now been questioned in the literature.^{4,8,9} In fact, negative appendectomy rates have become a quality metric for appendicitis. Today, research is centered on maximizing diagnostic accuracy with the use of imaging, risk-stratification scores, novel markers of appendicitis, and even treating uncomplicated appendicitis with antibiotics alone.^{5,16}

Negative appendectomy rates have declined year after year. In a recent ten-year review of the National Inpatient Sample database, Seetahal et al. found a consistent decline in the negative appendectomy rate from 14.7% in 1998 to 8.5% in 2007.⁹ In our multi-center study of adults in ACS-NSQIP participating hospitals, we report an overall negative appendectomy rate of 4.5%. This is one of the lowest rates reported in the literature.

Many attribute this decrease in the negative appendectomy rate to the introduction of clinical prediction rules such as the Alvarado score, which calculates the risk of acute appendicitis with eight weighted predictors.^{17,18} Others associate this decrease with the use of preoperative imaging studies. For example, Coursey et al. performed a retrospective study of 925 patients undergoing urgent appendectomies at their institution, and found an increase in preoperative imaging from 18.5% in 1998 to 93.2% in 2007.¹⁹ This coincided with a decrease in negative appendectomies in young women from 42.9% to 7.1%. A similar single-center study by Raman et al. showed a significant inverse relationship between the annual increase in rate of CT use and the annual decrease in overall rate of negative appendectomies in adults from 1996 to 2006.¹⁵ However, there are also large population-based studies that demonstrate no relationship between preoperative imaging and negative appendectomies.²⁰

In this study of the 2016 ACS-NSQIP database, the overall imaging utilization rate was 93.9%. Imaging studies were associated with lower negative appendectomy rates. Patients who proceeded to surgery without imaging had a NAR of 19.2%, while patients with one or more imaging studies had a NAR of 3.5%. Of the imaging modalities studied, CTs conferred the lowest negative appendectomy rate (2.5%) compared to US (9.7%) and MRI (7.1%). This association between imaging studies and NARs was also supported by the multivariable analysis, which showed that CT scanning was associated with lower odds of negative appendectomies, while ultrasounds had 155% higher odds of negative appendectomies.

Our findings are consistent with known sensitivity and specificity rates for different imaging modalities in the diagnosis of appendicitis. Studies show that CT scans can be more than 94% sensitive and specific in diagnosing acute appendicitis, but confer the risk of exposure to ionizing radiation.¹¹ While ultrasounds avoid radiation exposure, their sensitivities and specificities remain lower than CT (83% and 93%, respectively).¹¹ Furthermore, US studies may be challenging to obtain due to the limited availability of trained, experienced, sonologists who can reliably image the appendix.⁵ Overall, CT scans are widely accessible, highly sensitive adjuncts in the diagnosis of acute appendicitis.

If the CT scan was consistent with appendicitis, the NAR was as low as 1.4%. On the other hand, if the CT was indeterminate, the NAR was as high as 20.6% – similar to the NAR for patients who underwent surgery without any imaging at all. This trend was true for ultrasounds and MRIs as well. These findings reflect that 1. imaging studies have become one of the cornerstones of diagnosis for appendicitis in the modern era (as supported by the 93.9% imaging utilization rate in our study population) and that 2. if an imaging study is inconclusive, there may be additional value in obtaining a different scan to improve diagnostic accuracy.

Of all patients who underwent an appendectomy, 8.2% received two or three imaging films. The most common combination was an US and a CT (88.7%). In this cohort, 49.1% had an indeterminate US, while 31.2% had a negative US. The remaining 19.7% had an US that was consistent with appendicitis, but received the additional CT scan anyways.

If the patient had a negative or indeterminate US, the NAR after an additional CT (regardless of the CT result) was 9.1%, compared to 34.8% for a negative or indeterminate US alone. If the patient had an US consistent with appendicitis, the NAR after an additional CT was 0.6%, compared to 4.8% for a consistent US alone. In other words, surgeons made better decisions when they had both an ultrasound and a CT, compared to an US alone – even if the ultrasound was already consistent with appendicitis. This finding supports the idea that multiple imaging modalities can be used to decrease the rate of negative appendectomies. It also weakens the argument for staged diagnostic protocols in which ultrasounds are used as the initial imaging study and CTs are used to resolve indeterminate cases, as the additional CT is associated with better outcomes in all scenarios.^{21,22} This is a question that should be further explored with a cost-benefit analysis of multi-modality imaging versus negative appendectomies. These studies should also stratify by age and gender, as the additional value of a CT or US may vary in each population.

Many predictive factors for negative appendectomies have been identified in the literature. The most common include female gender, younger age, no CT, and lack of leukocytosis.^{23–25} Likewise, our study found higher odds of NA in patients who were female or had no imaging, and lower odds in patients with leukocytosis or SIRS/sepsis. We found an association between smoking and negative appendectomies, which may be a spurious association. Finally, patients with CTs had lower odds of NA, while patients with ultrasounds had higher odds of NA. This reflects the superiority of CT over ultrasound in terms of diagnostic accuracy.

There are several limitations to our study. First, the ACS-NSQIP database omits several variables that are commonly used in the diagnosis of appendicitis. For example, there is no information on history of present illness, physical exam, WBC differential, CRP levels, or the Alvarado score. These are possible confounding factors that could not be assessed in this study. Second, the timing and order of imaging studies could not be derived from the database. Third, we were not able to identify pregnant patients in our study, which could influence the choice of imaging. Finally, it is important to note that our findings only reflect the outcomes of adult patients who went to surgery; they do not reflect patients with low suspicion for appendicitis. Our study does not support the use of imaging for all patients who present with signs and symptoms concerning for appendicitis. Though our study focuses on the value of imaging, the history of present illness and physical exam remain the cornerstone of diagnosis for acute appendicitis.

Conclusion

The negative appendectomy rate in the 2016 ACS-NSQIP population is 4.5%. CTs are the most frequently used imaging modality and have lower negative appendectomy rates than ultrasound and MRI. Predictors of negative appendectomies include female gender, smoking history, and use of an ultrasound. The lack of CT, any imaging study, leukocytosis, or SIRS/sepsis is also a predictor of negative appendectomy. Obtaining a CT in addition to an ultrasound is associated with lower rates of negative appendectomy. This finding should be further explored with a cost-benefit analysis between multiple imaging modalities versus negative appendectomies.

Conflicts of interest

The authors have no conflicts of interest to report and have received no financial support in relation to this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.amjsurg.2018.12.072>.

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