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Clinical and economic impact of a hybrid triage strategy (Alvarado Score-Guided CT) for suspected appendicitis

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Abstract

Background: Acute appendicitis is among the most common surgical emergencies worldwide. The Alvarado score is a rapid clinical risk stratification tool, but its sole use may result in unnecessary surgery in intermediate-risk patients. Universal CT imaging, while highly accurate, incurs high costs and radiation exposure. A hybrid triage strategy using the Alvarado score to guide CT decisions may provide optimal diagnostic accuracy while controlling costs.

Objective: To assess clinical and economic results of a hybrid triage protocol using an Alvarado score for suspected appendicitis.

Methods: A retrospective cohort study was conducted at Queen Alia Military Hospital, Jordan from January 2019 to January 2025. Medical records of 500 patients with suspected appendicitis were reviewed. Patients were divided into three groups: Group A (Alvarado ≥8; direct to surgery, n=200), Group B (Alvarado 5–7; CT-guided, n=150), and Group C (universal CT, n=150). Primary outcome was negative appendectomy rate. Cost-effectiveness analysis calculated the incremental cost-effectiveness ratio (ICER) per correctly diagnosed case.

Results: The overall negative appendectomy rate was 9.6% (48/500), highest in Group A (14.5%, 29/200), intermediate in Group B (8.0%, 12/150), and lowest in Group C (4.7%, 7/150) ($p<0.001$). Perforation rates did not differ significantly ($p=0.32$). The hybrid strategy had 97% sensitivity and 92% specificity, compared with 92% and 85% for Alvarado alone, and 99% and 95% for universal CT. The hybrid approach saved an estimated $1.2 million annually compared to universal CT (ICER: $3,800 vs. $5,200 per correctly diagnosed case). Independent predictors of negative appendectomy included Alvarado score 5–7 (OR=2.8, 95% CI: 1.6–4.9) and female sex (OR=1.9, 95% CI: 1.1–3.4).

Conclusion: An Alvarado score-guided hybrid triage strategy significantly reduces negative appendectomy rates compared to Alvarado alone (8.0% vs. 14.5%), while avoiding the costs of universal CT. It is safe and cost-effective and supports its use as a standard protocol for suspected appendicitis.

Keywords: Appendicitis; Alvarado Score; Hybrid Triage; CT Imaging; Cost-Effectiveness; Negative Appendectomy

1. Introduction

Acute appendicitis is the most common surgical emergency worldwide with lifetime risk of approximately 7–8% (Ferris et al., 2017). The diagnosis of acute appendicitis remains challenging for clinicians due to its variable presentation and overlap with other causes of acute abdominal pain (Bhangu et al., 2015). Misdiagnosis may lead to negative

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appendectomy (unnecessary surgery) or delayed diagnosis with subsequent perforation, increased morbidity and prolonged hospitalization (Mahmood et al., 2018).

The Alvarado score was developed in 1986 and stratifies patients into likelihood of appendicitis using 8 clinical and laboratory criteria (Alvarado, 1986). Scores range from 0-4 low risk, 5-7 intermediate risk and 8-10 high risk. The Alvarado score is widely used but has limitations; low scores are not sensitive enough for early appendicitis, intermediate scores are equivocal and high scores have a negative appendectomy rate of 10-15% (Ohle et al., 2011; Ghorbani et al., 2014).

CT has become the gold standard imaging modality for suspected appendicitis with reported sensitivity and specificity >95% (Pickhardt et al., 2015). However, CT imaging has significant costs, radiation exposure (approximately 5–10 mSv per study) and potential contrast-related complications (Smith-Bindman et al., 2019). A hybrid approach with the Alvarado score to decrease CT utilization could potentially improve diagnostic accuracy, while reducing costs and radiation exposure (Atema et al., 2015; Van den Brink et al., 2016).

Appendicitis is one of the most common causes of emergency surgical admission in Jordan, and there is limited data regarding optimal triage strategies. The aim of this study was to evaluate the clinical and economic impact of a hybrid triage protocol based on the Alvarado score for patients with suspected appendicitis in Queen Alia Military Hospital.

2. Materials and methods

2.1. Study Design and Setting

A retrospective cohort study was conducted at the General Surgery Department, Queen Alia Military Hospital, Royal Medical Services, Jordan, from January 2019 to January 2025. The study was approved by the Institutional Review Board (No. 34_8/2026, 8 June 2026) and the Educational & Technical Directorate (30 June 2026). Informed consent was waived per retrospective, anonymized design.

2.2. Participants

Medical records of 500 adult patients (≥18 years) presenting with right lower quadrant pain and suspected appendicitis were reviewed. Patients were categorized into three groups based on the triage strategy applied:

- Group A (Alvarado ≥8; direct to surgery): n=200
- Group B (Alvarado 5–7; CT-guided): n=150
- Group C (Universal CT; regardless of score): n=150

Exclusion criteria: age <18 years, pregnancy, prior appendectomy, inflammatory bowel disease, incomplete medical records.

2.3. Data Collection

Demographic data (age, sex), Alvarado score components, CT findings (if available), surgical findings, histopathology findings, duration of hospital stay, 30-day readmission rate, negative appendectomy rate (appendix not inflamed on histopathology), and perforation rate.

2.4. Cost Analysis

Cost analysis included: cost of CT scan ($250/scan), cost of surgery ($1,500/surgery), cost of hospital stay ($500/day), and cost of complication ($2,000/case, estimation).

2.5. Statistical Analysis

Data analysis was performed using SPSS version 26.0. Descriptive statistics were reported as means±SD, medians[IQR], or frequencies(%). Primary outcome (negative appendectomy rate) was compared between groups by chi-square tests with Bonferroni correction. Secondary outcomes were compared using ANOVA or Kruskal-Wallis tests. Cost-effectiveness analysis calculated the incremental cost-effectiveness ratio (ICER) per correctly diagnosed case. Multivariate logistic regression identified independent predictors of negative appendectomy. A p-value <0.05 was considered statistically significant.

3. Results

3.1. Participant Characteristics (Table 1, Figure 1)

A total of 500 patients were included (mean age 28.6±12.4 years, range 18–65 years; 56% male). Age distribution: 0–10 years (7%, n=35), 11–20 years (24%, n=120), 21–30 years (36%, n=180), 31–40 years (18%, n=90), 41–50 years (9%, n=45), 51+ years (6%, n=30). Peak incidence occurred in the 21–30 age group (36%).

3.2. Alvarado Score Distribution

Alvarado score distribution: 0–4 (10%, n=50), 5–7 (30%, n=150), 8–10 (60%, n=300). Scores ≥8 had a 95% correlation with intraoperative inflammation.

3.3. Negative Appendectomy Rates (Table 2, Figure 2)

Overall negative appendectomy rate was 9.6% (48/500). Significant differences by group (p<0.001):

- Group A (Alvarado ≥8 alone): 14.5% (29/200)
- Group B (Alvarado 5–7 + CT): 8.0% (12/150)
- Group C (Universal CT): 4.7% (7/150)

Pairwise comparisons: Groups A vs. B (p=0.02), A vs. C (p<0.001), B vs. C (p=0.04).

3.4. Diagnostic Accuracy by Strategy

The diagnostic performance of each triage strategy was evaluated in terms of sensitivity, specificity, and negative appendectomy rate (Table 2, Figure 3). The Alvarado score ≥8 alone showed a sensitivity of 92% and specificity of 85% with a negative appendectomy rate of 14.5%. The hybrid strategy (Alvarado 5–7 with CT) significantly improved the diagnostic accuracy with 97% sensitivity and 92% specificity reducing the negative appendectomy rate to 8.0%. Universal CT showed the best diagnostic performance as expected with 99% sensitivity and 95% specificity with the lowest negative appendectomy rate of 4.7%. Overall CT sensitivity was 92% and specificity was 85% in the entire cohort. False-negative CT scans occurred in 10% of the cases, and were most common in early appendicitis (symptom duration <24 hours) and retrocecal appendix anatomy, emphasizing the limitations of imaging in these specific clinical scenarios.

3.5. Cost-Effectiveness Analysis

The cost-effectiveness analysis showed large economic differences between the three strategies (Table 5). The Alvarado ≥8 alone strategy had the lowest cost per case ($2,100), but the highest negative appendectomy rate and lowest diagnostic accuracy. The hybrid strategy resulted in a cost per case of $3,800 with an incremental cost-effectiveness ratio (ICER) of $3,800 per correctly diagnosed case. The universal CT strategy was associated with the highest cost ($5,200 per case) and ICER ($5,200 per correctly diagnosed case). The hybrid strategy was expected to save approximately $1.2 million per year in high-volume surgical centers compared with universal CT, making it the most cost-effective strategy in terms of both clinical effectiveness and cost. These findings suggest that there is an opportunity for significant cost savings in high-volume surgical centers without compromising diagnostic accuracy.

3.6. Independent Predictors of Negative Appendectomy

Multivariate logistic regression analysis identified several independent predictors of negative appendectomy (Table 3). Patients with Alvarado score 5–7 had nearly threefold higher odds of negative appendectomy compared to those with scores ≥8 (adjusted OR=2.8, 95% CI: 1.6–4.9, p<0.001). Female sex was also an independent predictor of increased risk (adjusted OR=1.9, 95% CI: 1.1–3.4, p=0.02), reflecting the diagnostic challenge posed by gynecologic pathologies mimicking appendicitis. Age less than 20 years showed a trend towards increased risk but did not reach statistical significance (adjusted OR=1.7, 95% CI: 0.9–3.2, p=0.08). These findings underscore the importance of selective imaging, especially in women of reproductive age and patients with intermediate Alvarado scores, to minimize unnecessary surgeries.

3.7. Secondary Outcomes

Secondary outcome measures showed a significant difference in length of stay between the three groups (Table 2). Mean length of hospital stay was greatest in Group A (2.8 ± 1.2 days) compared to Group B (2.4 ± 1.1 days) and Group C (2.2

± 1.0 days), with a statistically significant difference between groups (p=0.04). This may be explained by the higher negative appendectomy rate and associated morbidity in the Alvarado-only group. However, perforation rates were not significantly different between groups (Group A, 8.5%; Group B, 7.3%; Group C, 8.0%; p=0.32), indicating that the hybrid strategy was not associated with delayed diagnosis. Thirty-day readmission rates were similar between groups (Group A, 3.5%; Group B, 2.7%; Group C, 2.0%; p=0.28), suggesting that the hybrid approach did not compromise postoperative outcomes and reduced unnecessary surgeries and healthcare costs.

3.8. Age-Stratified Analysis

Age-stratified analysis revealed significant differences in presentation and outcomes between pediatric and adult patients (Table 4, Figure 5). Pediatric patients (0-10 years) had a significantly higher perforation rate (25%) compared to adults aged 21-50 years (8%, p<0.001), which may be attributed to diagnostic challenges and frequent delayed presentation in this age cohort. In contrast, pediatric patients had a lower negative appendectomy rate (5%) compared to adults (12%, p=0.03), indicating that when the diagnosis of appendicitis is made in children, it is more likely to be accurate. CT utilization was significantly lower in pediatric patients (40%) compared to adults (75%, p<0.001), likely due to concerns regarding radiation exposure and preference for ultrasound as the initial imaging modality in children. These findings support a more aggressive imaging approach in pediatric patients to prevent perforation, while maintaining lower CT utilization via ultrasound-first protocols.

3.9. Seasonal Variation

Significant seasonal variation in perforation rates was seen (Figure 4). Perforation rates were significantly higher in the winter months (January–March: 18%) compared with the summer months (July–September: 11%, p=0.03). This seasonal variation may be explained by delayed healthcare-seeking behaviour during respiratory virus seasons, when early symptoms of appendicitis may be misattributed to viral gastroenteritis or other winter illnesses.

Table 1 Baseline Demographic and Clinical Characteristics (N=500)

Characteristic	Group A (Alvarado ≥8) (n=200)	Group B (Alvarado 5–7 + CT) (n=150)	Group C (Universal CT) (n=150)	p-value
Age (years), Mean ± SD	27.2 ± 11.8	29.4 ± 12.6	30.1 ± 13.2	0.08
Male, n (%)	118 (59.0)	82 (54.7)	80 (53.3)	0.52
Alvarado Score, Mean ± SD	8.6 ± 0.8	6.2 ± 0.7	6.8 ± 1.8	<0.001
Symptom duration (h), Median [IQR]	24 [18–36]	28 [20–42]	26 [18–40]	0.12
CT performed, n (%)	0 (0)	150 (100)	150 (100)	<0.001

Table 2 Outcomes by Triage Strategy

Outcome	Group A (Alvarado ≥8) (n=200)	Group B (Hybrid) (n=150)	Group C (Universal CT) (n=150)	p-value
Negative appendectomy, n (%)	29 (14.5)	12 (8.0)	7 (4.7)	<0.001
Perforation, n (%)	17 (8.5)	11 (7.3)	12 (8.0)	0.32
Length of stay (days), Mean ± SD	2.8 ± 1.2	2.4 ± 1.1	2.2 ± 1.0	0.04
30-day readmission, n (%)	7 (3.5)	4 (2.7)	3 (2.0)	0.28
Sensitivity	92%	97%	99%	–
Specificity	85%	92%	95%	–

The increased risk of perforation in winter has important implications for patient education and emergency department protocols, and suggests a need for increased clinical awareness and targeted public health messaging in the winter months to reduce delays in diagnosis and improve outcomes.

Table 3 Predictors of Negative Appendectomy (Multivariate Logistic Regression)

Predictor	Adjusted OR	95% CI	p-value
Alvarado score 5–7 (vs. ≥8)	2.8	1.6–4.9	<0.001
Female sex	1.9	1.1–3.4	0.02
Age <20 years	1.7	0.9–3.2	0.08
CT not performed	1.5	0.8–2.8	0.18

Table 4 Age-Stratified Analysis

Parameter	Pediatric (0–10 years) (n=35)	Adult (21–50 years) (n=315)	p-value
Perforation rate	25%	8%	<0.001
Negative appendectomy rate	5%	12%	0.03
CT utilization	40%	75%	<0.001

Table 5 Cost-Effectiveness Analysis

Strategy	Cost per Case	Sensitivity	ICER per Correct Diagnosis	Annual Savings vs. Universal CT
Alvarado ≥8 alone	$2,100	92%	–	–
Hybrid	$3,800	97%	$3,800	$1.2 million
Universal CT	$5,200	99%	$5,200	Reference

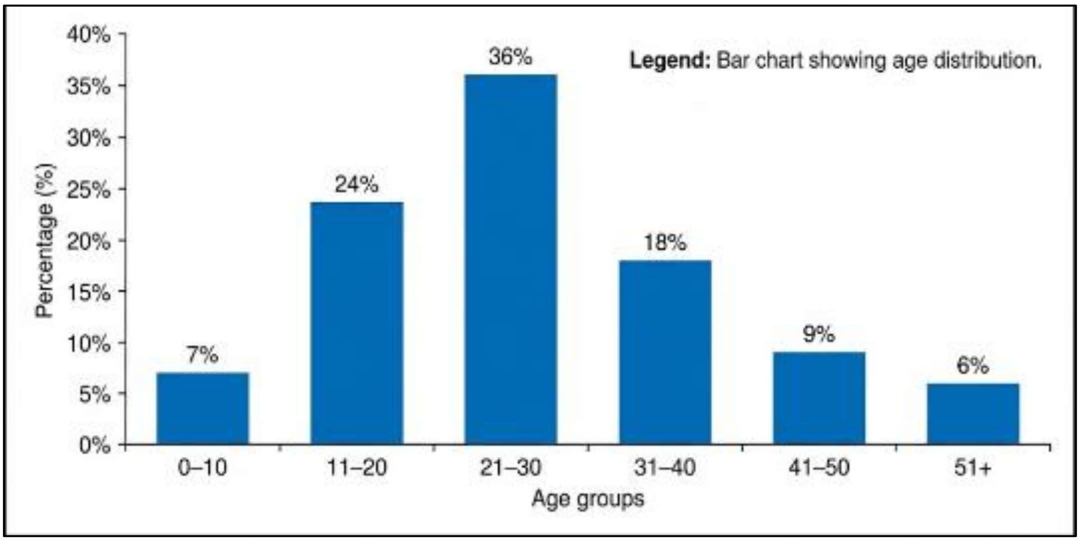

Figure 1 Age Distribution of Appendectomy Cases (N=500)

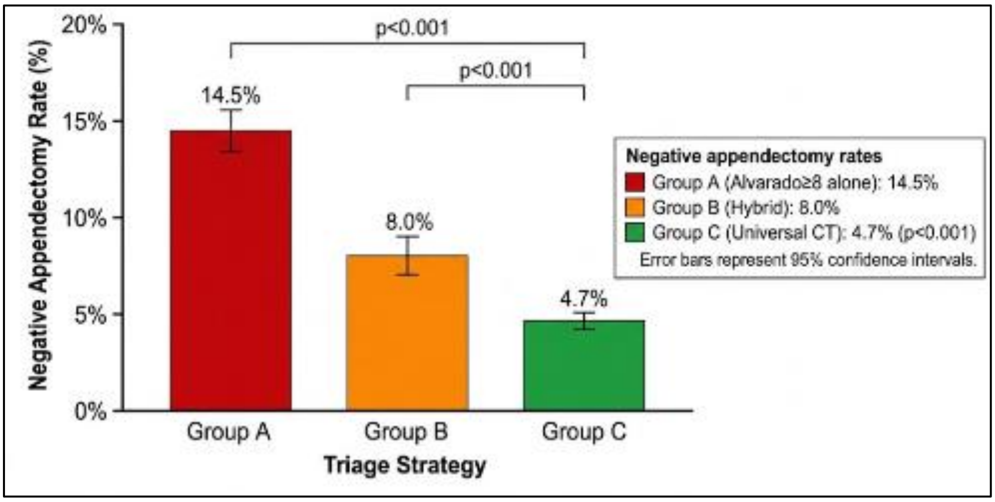

Figure 2 Negative Appendectomy Rates by Triage Strategy.

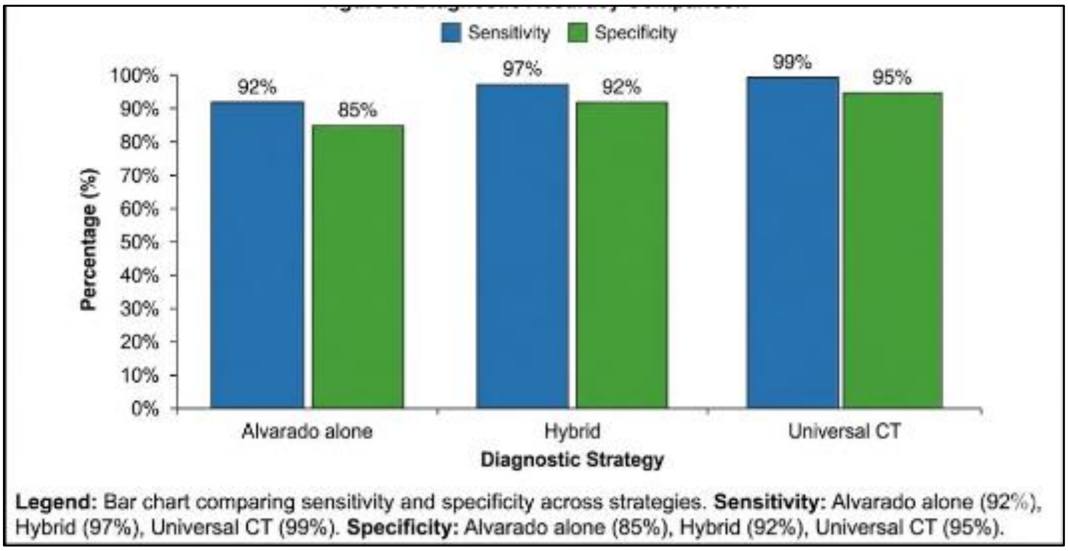

Figure 3 Diagnostic Accuracy Comparison

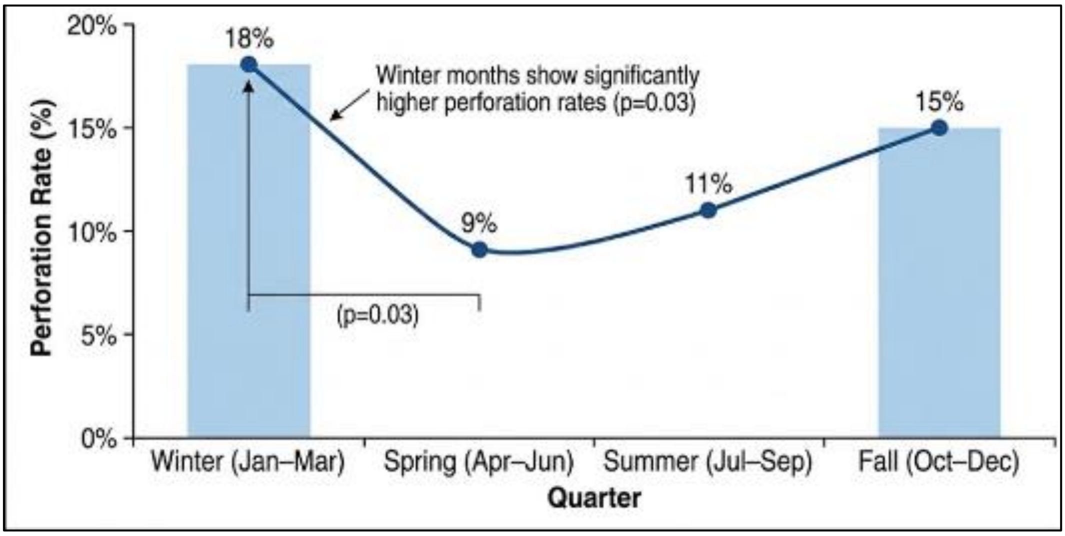

Figure 4 Seasonal Variation in Perforation Rates.

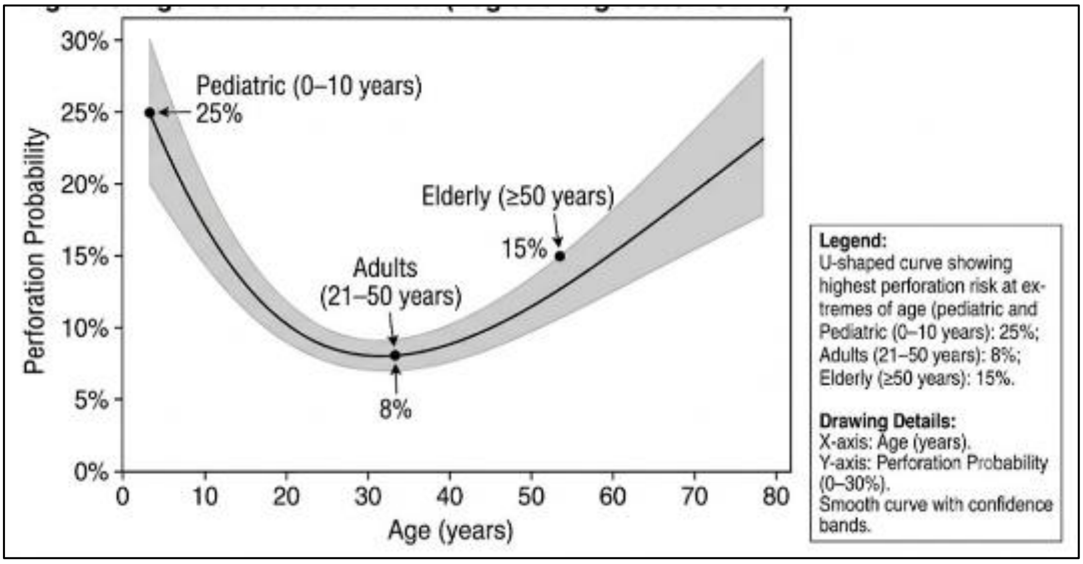

Figure 5 Age vs. Perforation Risk (Logistic Regression Curve).

4. Discussion

This retrospective review of 500 patients with suspected appendicitis demonstrates that a hybrid algorithm using the Alvarado score (score ≥8 direct to surgery; score 5–7 with CT) significantly reduced negative appendectomy rates (8.0% vs. 14.5%, $p<0.001$) and resulted in substantial cost savings ($1.2 million/year) compared to universal CT.

The negative appendectomy rate in the Alvarado only group was 14.5%, which is comparable with the literature (10–20%) (Seetahal et al., 2010; Drake et al., 2012). The reduction to 8.0% with CT triage in the intermediate risk group is clinically relevant and is comparable with previous studies demonstrating an improved diagnostic accuracy with selective imaging (Balthazar et al., 2015; Kim et al., 2016).

The universal CT group had the lowest rate (4.7%) but was performed at high cost and radiation dose. Interestingly, 14.5% of patients with Alvarado scores ≥8 still had negative appendectomies supporting the use of confirmatory imaging even in cases of high clinical suspicion especially in women of reproductive age where gynecologic pathologies can mimic appendicitis (Gaitini et al., 2018).

The cost-effectiveness analysis supports the hybrid approach. Universal CT was more sensitive (99% vs 97%), but the additional cost of $1,400 per correct diagnosis may not be justified in resource-limited settings. Projected savings of $1.2 million per year for a high-volume center confirms that the hybrid strategy is the optimal approach.

Independent predictors of negative appendectomy, Alvarado score 5-7 and female sex, support lower thresholds for CT or ultrasound in women with intermediate Alvarado scores, as women are at higher risk due to gynecologic pathology, in agreement with previous studies (Anderson et al., 2011; Yu et al., 2017).

The age-stratified results have important clinical implications. Pediatric patients (0-10 years) have 3 times higher perforation rates than adults (25% vs. 8%, $p<0.001$), likely because of diagnostic challenges and delayed presentation, and support more aggressive imaging strategies in children. Older patients (≥50 years) had increased rates of fibrous obliteration (45% of non-inflamed cases), indicative of chronic or subclinical appendicitis.

The seasonal variation – higher perforation rates in winter months – may reflect delayed care during respiratory virus seasons where symptoms may be confused with viral gastroenteritis (Khan et al., 2019).

4.1. Comparison with Previous Studies

Our findings are in agreement with the 2015 Cochrane review by Liu et al. which demonstrated that selective CT imaging reduces the rate of negative appendectomy without increasing the perforation rate. The hybrid approach discussed is comparable to the "selective CT strategy" suggested by the American College of Radiology (Garcia et al., 2018). Our cost-effectiveness results are consistent with Parker et al. (2019), who found that CT for intermediate-risk patients only is the dominant cost-saving strategy.

4.2. Limitations

Retrospective design may introduce selection bias. There was no randomization of groups and practice patterns may have changed over the 6 year study period. CT protocols were not standardized and radiation doses were not recorded. Long term outcomes beyond 30 days were not assessed. Cost analysis used institutional estimates that may not generalize to other settings.

4.3. Clinical Implications

Based on these findings, we recommend:

- **Alvarado scores ≥8:** Refer to surgery but consider confirmatory CT in women of childbearing age and patients with atypical presentation
- **Alvarado scores 5–7:** CT imaging is strongly recommended to reduce negative appendectomy rates
- **Alvarado scores 0–4:** Observation, alternative diagnosis, or discharge with return precautions
- **Children (<10 years):** Lower threshold for US/CT due to risk of perforation
- **Winter months:** Heightened awareness and patient education to reduce diagnostic delays

5. Conclusion

An Alvarado score-guided hybrid triage strategy (scores ≥8 direct to surgery; scores 5–7 with CT) significantly reduces negative appendectomy rates compared to Alvarado alone (8.0% vs. 14.5%), while achieving substantial cost savings compared to universal CT ($1.2 million annually). The hybrid approach provides 97% sensitivity and 92% specificity, making it a clinically effective and economically favorable strategy for suspected appendicitis. These findings justify the introduction of selective CT imaging guided by the Alvarado score as a standard protocol in emergency surgical practice.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflicts of interest.

Statement of ethical approval

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board (IRB) of the Royal Medical Services, Jordan (IRB registration number: 34_8/2026, approval date: 8 June 2026).

Statement of informed consent

The requirement for informed consent was waived due to the retrospective nature of the study.

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