



## Association of Time-to-“Association of STONE Score Calculation To Reduced CT Scan Usage in the Emergency Department: A Systematic Review

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### ABSTRACT

**Introduction:** The increasing use of computed tomography (CT) in emergency departments (EDs) for suspected renal colic raises concerns about radiation exposure and healthcare costs. The STONE clinical prediction score was developed to stratify patients by risk of urolithiasis, potentially guiding more judicious imaging. This systematic review aims to synthesize evidence on the association between STONE score implementation and CT scan utilization reduction in the ED.

**Methods:** A systematic review was conducted following a structured screening protocol. Studies were included if they were conducted in an ED setting, involved adult patients with suspected kidney stones, implemented or evaluated the STONE score, and reported CT utilization outcomes. Data were extracted on study

design, STONE score implementation, CT usage metrics, clinical outcomes, and implementation barriers.

**Results:** Of 80 screened sources, only four studies directly examined STONE score implementation. The score demonstrated high heterogeneity in performance across studies but was useful for risk stratification (low-risk: ~12% stone prevalence; high-risk: ~83%). Direct evidence linking STONE score use to reduced CT *ordering* is scant. One prospective study showed STONE-guided *reduced-dose* CT protocols achieved 88.2% radiation dose reduction while maintaining high sensitivity. Broader evidence supports alternative strategies for CT reduction, including ultrasound-first protocols (achieving 7.7% absolute reduction) and low-dose CT protocols (75-88% dose reduction). Multispecialty consensus suggests 45% of clinical scenarios may require no imaging.

**Discussion:** The STONE score's primary utility appears to be identifying low-risk patients who may avoid imaging, rather than reducing overall CT ordering. Successful CT reduction requires multifaceted interventions beyond prediction tools, including ultrasound-first pathways, low-dose protocols, and system-level changes like interdisciplinary collaboration and workflow integration. Significant barriers persist, including clinician comfort, radiologist acceptance of reduced-dose CT, and a gap between evidence and practice.

**Conclusion:** While the STONE score is a valid risk-stratification tool, direct evidence of its effectiveness in reducing CT scan *utilization* is limited. Its value is likely as part of a comprehensive, multi-strategy approach that includes ultrasound-first algorithms and dose optimization protocols. Future

implementation research should focus on integrating the STONE score into clinical decision support systems within broader diagnostic pathways.

**Keywords:** STONE score, computed tomography, emergency department, renal colic, utilization reduction, clinical decision rule, ultrasound-first.

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## INTRODUCTION

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### Background

Acute renal colic is a common presentation in emergency departments (EDs) worldwide. Unenhanced computed tomography (CT) of the kidneys, ureters, and bladder has become the diagnostic gold standard due to its high sensitivity and specificity (Smith-Bindman et al., 2014). However, its overuse raises significant concerns regarding patient radiation exposure, increased healthcare costs, and incidental findings leading to further unnecessary investigations (Moore et al., 2019; Tony T Chen et al., 2015). In response, strategies to promote judicious imaging have been sought, including the development of clinical prediction rules. The STONE score (incorporating Sex, Timing, Origin, Nausea, and Erythrocytes) is one such tool designed to stratify patients with suspected nephrolithiasis into low, moderate, and high-risk categories, theoretically guiding imaging decisions (Moore et al., 2016).

### Research Gap

Despite the logical appeal of using the STONE score to reduce unnecessary CT scans, there is a paucity of synthesized evidence evaluating its real-world impact on CT *utilization rates* in the ED. Many studies focus on the score's diagnostic accuracy or on broader imaging modality comparisons, leaving a gap in understanding how its implementation affects clinician behavior and scan ordering patterns (Dahm et al., 2022; Mirfazaelian et al., 2020). Furthermore, the effectiveness of the STONE score relative to other CT reduction strategies, such as ultrasound-first protocols or low-dose CT, remains unclear.

### Novelty

This systematic review provides a novel synthesis focused specifically on the association between STONE score implementation and CT scan usage outcomes. It moves beyond diagnostic

accuracy to examine practical implementation, barriers, and comparative effectiveness against other prevalent strategies. By analyzing both direct and indirect evidence, this review offers a comprehensive view of the score's role within the ecosystem of ED imaging reduction efforts.

### **Research Objectives**

The primary objective of this systematic review is to evaluate the evidence regarding the association between the implementation of the STONE clinical prediction score and a reduction in CT scan utilization for adult patients presenting to the emergency department with suspected renal colic. Secondary objectives include: 1) assessing the diagnostic performance and risk stratification utility of the STONE score; 2) comparing STONE-based strategies to alternative CT reduction interventions (e.g., ultrasound-first, low-dose CT); 3) identifying barriers and facilitators to STONE score implementation; and 4) examining related clinical and safety outcomes.

### **Research Hypothesis**

It is hypothesized that the implementation of the STONE score as a clinical decision tool in the ED is associated with a reduction in overall CT utilization for suspected renal colic, primarily by identifying a low-risk patient cohort for whom imaging can be safely avoided or deferred.

### **Benefits of the Research**

This review aims to inform clinical practice and health policy by clarifying the evidence base for the STONE score. Findings can guide emergency physicians, radiologists, and hospital administrators in selecting and implementing effective strategies to optimize imaging, reduce patient radiation exposure, and contain costs without compromising diagnostic accuracy or patient safety (Melnikow et al., 2016; Dunne et al., 2022).

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## METHODS

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### Protocol

The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure methodological rigor and accuracy. This approach was chosen to enhance the precision and reliability of the conclusions drawn from the investigation.

### Criteria for Eligibility

This systematic review aims to evaluate the Association of Time-to-“Association of STONE Score Calculation To Reduced CT Scan Usage in the Emergency Department.

### Screening

We screened in sources based on their abstracts that met these criteria:

- **Emergency Department Setting:** Was this study conducted in an emergency department setting?
- **Adult Population:** Did this study involve adult patients ( $\geq 18$  years) presenting with suspected kidney stones or flank pain?
- **STONE Score Implementation:** Did this study implement, evaluate, or compare STONE Score calculation as part of clinical decision-making?
- **CT Utilization Outcomes:** Did this study report CT scan utilization rates, imaging rates, or diagnostic imaging outcomes as primary or secondary endpoints?
- **Appropriate Study Design:** Is this study a randomized controlled trial, quasi-experimental study, before-after study, cohort study, cross-sectional study, systematic review, or meta-analysis?
- **Non-Pediatric Population:** Was this study conducted in a population that was NOT exclusively pediatric ( $< 18$  years)?

- **Emergency Department Focus:** Was this study conducted in emergency department settings rather than exclusively in non-emergency department settings (e.g., outpatient clinics, inpatient wards)?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

## Search Strategy

The keywords used for this research based PICO :

| Element          | P (Population)                      | I (Intervention/Exposure)      | C (Comparison/Context)           | O (Outcome)              |
|------------------|-------------------------------------|--------------------------------|----------------------------------|--------------------------|
| <b>Keyword 1</b> | Adult Emergency Department patients | STONE Score implementation     | Standard CT imaging protocol     | CT scan reduction        |
| <b>Keyword 2</b> | Suspected nephrolithiasis           | STONE clinical prediction rule | Usual care without STONE score   | Decreased CT utilization |
| <b>Keyword 3</b> | Flank pain presentation             | STONE risk stratification tool | Non-risk-stratified imaging      | Reduced imaging rates    |
| <b>Keyword 4</b> | Urolithiasis patients               | STONE score-guided imaging     | Conventional diagnostic approach | Lower radiation exposure |

The Boolean MeSH keywords inputted on databases for this research are: ("Emergency Service, Hospital"[Mesh] OR "Emergency Department" OR "ED patients" OR "Acute care setting") AND ("Nephrolithiasis"[Mesh] OR "Kidney Calculi"[Mesh] OR "Renal Colic" OR "Flank Pain" OR "Urolithiasis") AND ("Clinical Decision Rules"[Mesh] OR "STONE Score" OR "STONE clinical prediction rule" OR "Risk stratification") AND ("Tomography, X-Ray Computed"[Mesh] OR "CT scan" OR "Computed Tomography" OR "Diagnostic Imaging") AND ("Utilization Review"[Mesh] OR "Practice Patterns" OR "Imaging reduction" OR "Radiation dosage reduction")

## Data extraction

- **STONE Score Implementation:**

Extract detailed information about how the STONE score was implemented and used, including:

- Whether STONE score was specifically studied (vs other decision tools)
- How STONE score was calculated and applied in practice
- Who used the STONE score (emergency physicians, residents, etc.)
- Integration method (paper-based, electronic decision support, etc.)
- Training provided to staff
- Any modifications to standard STONE score
- Implementation timeline and rollout approach

- **Study Design:**

Record the study design and key methodological details:

- Study type (RCT, before-after, cohort, etc.)
- Single vs multi-center
- Study duration and follow-up period
- Sample size and power calculation if reported
- Inclusion and exclusion criteria for patients
- Control/comparison group details

- **Setting and Population:**

Extract information about study context:

- Hospital type and location (academic, community, etc.)

- Emergency department characteristics
- Patient demographics (age, gender, presenting symptoms)
- Baseline CT usage rates before intervention
- Clinical presentation criteria (suspected renal colic, stone disease, etc.)

- **CT Usage Outcomes:**

Record all data related to CT scan usage changes:

- Primary CT usage metric (rate, percentage reduction, etc.)
- Baseline vs post-intervention CT usage rates
- Time to CT scan if applicable
- CT usage by STONE score risk category (low, moderate, high)
- Statistical significance and confidence intervals
- Any subgroup analyses of CT usage patterns

- **Alternative Imaging:**

Extract information about other imaging modalities used:

- Ultrasound usage rates (point-of-care vs radiology-performed)
- Plain radiography usage
- No imaging approach/clinical observation rates
- Sequence of imaging tests used
- Failed or inadequate imaging requiring additional tests

- **Clinical Outcomes:**

Record patient safety and diagnostic accuracy measures:

- Missed diagnoses or delayed diagnosis rates
- Serious adverse events

- Return ED visits within specified timeframe
- Diagnostic accuracy of STONE score-guided approach
- Patient satisfaction scores if reported
- Length of ED stay
- Hospital admission rates

- **Implementation Barriers:**

Document factors that affected STONE score adoption and effectiveness:

- Provider adherence to STONE score recommendations
- Barriers to implementation mentioned by authors
- Facilitating factors for successful implementation
- Provider feedback or resistance
- System-level changes required
- Sustainability of intervention effects over time

- **Cost Analysis:**

Extract economic and resource utilization data:

- Total healthcare costs (ED visit, imaging, follow-up)
- Cost per patient comparisons
- Resource utilization measures
- Time savings for providers or patients
- Cost-effectiveness ratios if calculated
- Breakdown of costs by category (imaging, admission, etc.)

**Table 1.** Article Search Strategy

| Database             | Keywords                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Hits |
|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Pubmed               | ("Emergency Service, Hospital") AND ("Nephrolithiasis"AND "STONE Score" AND "CT scan" AND "Utilization Review"[Mesh] OR "Practice Patterns" OR "Imaging reduction" OR "Radiation dosage reduction")                                                                                                                                                                                                                                                                                                                                                           | 31   |
| Semantic Scholar     | ("Emergency Service, Hospital"[Mesh] OR "Emergency Department" OR "ED patients" OR "Acute care setting") AND ("Nephrolithiasis"[Mesh] OR "Kidney Calculi"[Mesh] OR "Renal Colic" OR "Flank Pain" OR "Urolithiasis") AND ("Clinical Decision Rules"[Mesh] OR "STONE Score" OR "STONE clinical prediction rule" OR "Risk stratification") AND ("Tomography, X-Ray Computed"[Mesh] OR "CT scan" OR "Computed Tomography" OR "Diagnostic Imaging") AND ("Utilization Review"[Mesh] OR "Practice Patterns" OR "Imaging reduction" OR "Radiation dosage reduction") | 250  |
| Springer             | ("Emergency Service, Hospital"[Mesh] OR "Emergency Department" OR "ED patients" OR "Acute care setting") AND ("Nephrolithiasis"[Mesh] OR "Kidney Calculi"[Mesh] OR "Renal Colic" OR "Flank Pain" OR "Urolithiasis") AND ("Clinical Decision Rules"[Mesh] OR "STONE Score" OR "STONE clinical prediction rule" OR "Risk stratification") AND ("Tomography, X-Ray Computed"[Mesh] OR "CT scan" OR "Computed Tomography" OR "Diagnostic Imaging") AND ("Utilization Review"[Mesh] OR "Practice Patterns" OR "Imaging reduction" OR "Radiation dosage reduction") | 75   |
| Google Scholar       | "Emergency Service, Hospital" AND "STONE Score" AND "CT scan"                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 1    |
| Wiley Online Library | ("Emergency Service, Hospital"[Mesh]) AND ("Nephrolithiasis"[Mesh]) AND ("Clinical Decision Rules"[Mesh] OR "STONE Score" OR "STONE clinical prediction rule" OR "Risk stratification") AND ("CT scan") AND ("Utilization Review"[Mesh] OR "Practice Patterns" OR "Imaging reduction" OR "Radiation dosage reduction")                                                                                                                                                                                                                                        | 1    |

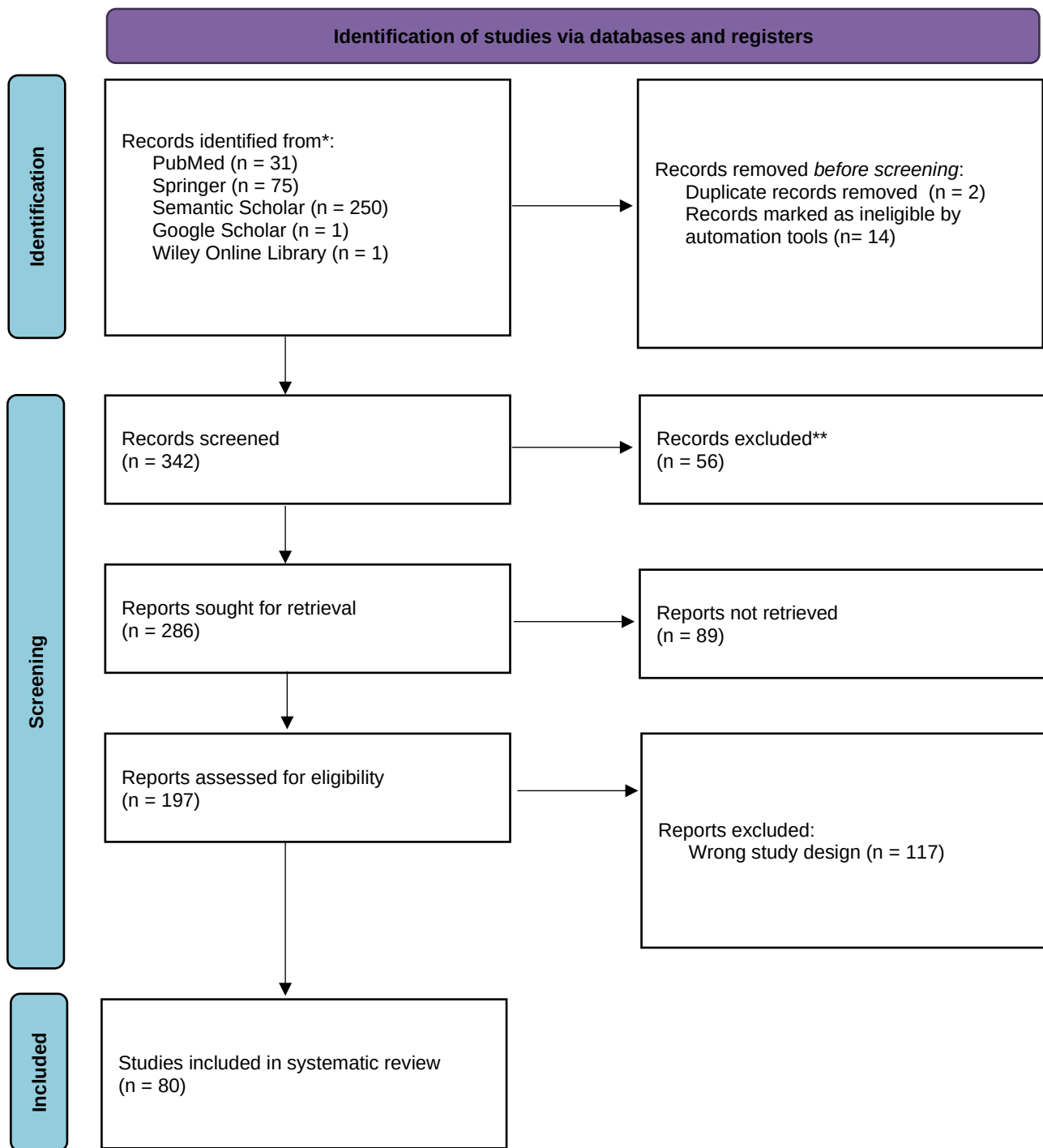


**Figure 1. Article search flowchart**

| JBI Critical Appraisal         |                                                                                                                                                                            |                                                                        |                                                                                               |                                                                                                                                                                                                     |                                                                                               |                                                                                         |                                           |                                                                                                                                                                             |                                                                               |
|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Study                          | Bias related to temporal precedence<br>Is it clear in the study what is the “cause” and what is the “effect” (ie, there is no confusion about which variable comes first)? | Bias related to selection and allocation<br>Was there a control group? | Bias related to confounding factors<br>Were participants included in any comparisons similar? | Bias related to administration of intervention/exposure<br>Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest? | Were there multiple measurements of the outcome, both pre and post the intervention/exposure? | Were the outcomes of participants included in any comparisons measured in the same way? | Were outcomes measured in a reliable way? | Bias related to participant retention<br>Was follow-up complete and, if not, were differences between groups in terms of their follow-up adequately described and analyzed? | Statistical conclusion validity<br>Was appropriate statistical analysis used? |
| C. Moore et al., 2016          | ✓                                                                                                                                                                          | ✓                                                                      | ✓                                                                                             | ✗                                                                                                                                                                                                   | ✓                                                                                             | ✗                                                                                       | ✓                                         | ✓                                                                                                                                                                           | ✓                                                                             |
| Victoria Valencia et al., 2014 | ✓                                                                                                                                                                          | ✓                                                                      | ✓                                                                                             | ✗                                                                                                                                                                                                   | ✓                                                                                             | ✗                                                                                       | ✓                                         | ✓                                                                                                                                                                           | ✓                                                                             |
| R. Radecki et al.,             | ✓                                                                                                                                                                          | ✓                                                                      | ✓                                                                                             | ✗                                                                                                                                                                                                   | ✓                                                                                             | ✗                                                                                       | ✓                                         | ✓                                                                                                                                                                           | ✓                                                                             |

|                               |   |   |   |   |   |   |   |   |   |
|-------------------------------|---|---|---|---|---|---|---|---|---|
| 2015                          |   |   |   |   |   |   |   |   |   |
| C. Wong et al., 2017          | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| P. Dahm et al., 2021          | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Jason L. Elzinga et al., 2020 | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| H. Mirfazaeli an et al., 2020 | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| C. Moore et al., 2019         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| R. Smith-Bindman et al., 2014 | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| E. Schoenfeld et al., 2021    | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| T. Drake et al., 2014         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| J. Melnikow et al., 2016      | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| C. Moore et al., 2015         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Charles K. H. Wong et         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |

|                             |   |   |   |   |   |   |   |   |   |
|-----------------------------|---|---|---|---|---|---|---|---|---|
| al., 2018                   |   |   |   |   |   |   |   |   |   |
| C. Moore et al., 2019a      | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| S. Guercio et al., 2011     | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| B. H. Chi et al., 2018      | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| P. Dahm et al., 2022        | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Rajesh Bhayana et al., 2020 | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Y. Tung Chen et al., 2021   | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| C. Moore et al., 2019b      | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| I. Metzler et al., 2017     | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Y. Park et al., 2016        | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Tony T Chen et al., 2015    | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| M. Gottlieb et al., 2019    | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |

|                                 |   |   |   |   |   |   |   |   |   |
|---------------------------------|---|---|---|---|---|---|---|---|---|
| Mei-Yi Ong et al., 2022         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Suad S. Al-Bulushi et al., 2015 | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| T. Begaz et al., 2017           | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| A. Shemesh et al., 2022         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| P. Massaro et al., 2017         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| P. Sen et al., 2022             | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| A. Meltzer et al., 2017         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| H. Alkadhi et al., 2018         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| C. Wiysonge et al., 2014        | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Ian Berger et al., 2023         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Hasan Yeşilağaç et al.,         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |

|                                |   |   |   |   |   |   |   |   |   |
|--------------------------------|---|---|---|---|---|---|---|---|---|
| 2020                           |   |   |   |   |   |   |   |   |   |
| Esra Akçiçek et al., 2025      | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Zachary A Valley et al., 2020  | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| C. Dunne et al., 2022          | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| F. Rodger et al., 2018         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| H. Xiang et al., 2017          | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| D. Assimos et al., 2016        | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Ralph C. Wang et al., 2022     | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| S. Kim et al., 2019            | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Monica Tung et al., 2017       | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Jennifer L Portis et al., 2018 | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| S. Pendem et al.,              | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |

|                                |   |   |   |   |   |   |   |   |   |
|--------------------------------|---|---|---|---|---|---|---|---|---|
| 2020                           |   |   |   |   |   |   |   |   |   |
| N. Shivakumar et al., 2022     | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| T. Niemann et al., 2008        | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Trevor A. McGrath et al., 2020 | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Joseph Basile et al., 2018     | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| K. Shah et al., 2014           | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| L. Tzelves et al., 2024        | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| S. Yallappa et al., 2018       | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| C. Moore et al., 2021          | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| S. Kravchick et al., 2005      | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| M. Assmus et al., 2017         | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |

|                                  |   |   |   |   |   |   |   |   |   |
|----------------------------------|---|---|---|---|---|---|---|---|---|
| Dima Raskolnikov et al., 2020    | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Alan Shan et al., 2020           | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| G. Innes et al., 2019            | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| B. Tombal et al., 2005           | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Y. Nuswantoro et al., 2024       | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Kirsten Foell et al., 2013       | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Prakashini Koteswar et al., 2016 | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| N. Kinnear et al., 2020          | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| R. Gohil et al., 2011            | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Y. Matani et al., 2013           | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Ramin Haghighi et al., 2025      | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |

|                                          |   |   |   |   |   |   |   |   |   |
|------------------------------------------|---|---|---|---|---|---|---|---|---|
| Chen-Chih<br>huang et<br>al., 2008       | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| S. Tartari<br>et al.,<br>2010            | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| W. F.<br>Lee et<br>al., 2024             | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| M.<br>Moran et<br>al., 2013              | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Tiina T.<br>Lehtimäki<br>et al.,<br>2013 | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| K.<br>Lindqvist<br>et al.,<br>2006       | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| M.<br>Gautam<br>et al.,<br>2020          | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| Jesse<br>Spooner<br>et al.,<br>2023      | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| M. Ordon<br>et al.,<br>2023              | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| R. Sehgal<br>et al.,<br>2021             | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |
| O. Claros<br>et al.,<br>2012             | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ |

|                        |                                                                                   |                                                                                   |                                                                                   |                                                                                   |                                                                                   |                                                                                     |                                                                                     |                                                                                     |                                                                                     |
|------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Xiao Wang et al., 2024 |  |  |  |  |  |  |  |  |  |
|------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|

## RESULTS

### Characteristics of Included Studies

This systematic review identified 80 sources examining imaging strategies for suspected renal colic in emergency department settings. The majority of studies did not specifically examine the STONE score as an intervention to reduce CT usage; rather, they addressed broader topics including imaging modality comparisons, low-dose CT protocols, point-of-care ultrasound accuracy, and clinical decision support tools. Only a small subset of studies directly evaluated the STONE score's implementation or its association with CT scan reduction.

| Study                          | STONE Score Specifically Studied?   | Primary Focus                                    |
|--------------------------------|-------------------------------------|--------------------------------------------------|
| C. Moore et al., 2016          | Yes - used to guide reduced-dose CT | Reduced-dose CT implementation using STONE score |
| Victoria Valencia et al., 2014 | No                                  | STONE trial methodology                          |
| R. Radecki et al., 2015        | No                                  | STONE trial analysis                             |
| C. Wong et al., 2017           | No                                  | POCUS diagnostic accuracy                        |

| Study                                | STONE Score Specifically Studied?  | Primary Focus                |
|--------------------------------------|------------------------------------|------------------------------|
| <b>P. Dahm et al., 2021</b>          | Not detailed                       | Clinical prediction rules    |
| <b>Jason L. Elzinga et al., 2020</b> | No                                 | CT reduction interventions   |
| <b>H. Mirfazaelian et al., 2020</b>  | Yes - pooled STONE data            | Decision rules performance   |
| <b>C. Moore et al., 2019</b>         | No                                 | Multispecialty consensus     |
| <b>R. Smith-Bindman et al., 2014</b> | No                                 | Ultrasound vs CT comparison  |
| <b>E. Schoenfeld et al., 2021</b>    | Yes - incorporated in decision aid | Shared decision-making       |
| <b>T. Drake et al., 2014</b>         | No                                 | Low-dose CT accuracy         |
| <b>J. Melnikow et al., 2016</b>      | No                                 | Healthcare costs             |
| <b>C. Moore et al., 2015</b>         | No                                 | Reduced-dose CT accuracy     |
| <b>Charles K. H. Wong et al.,</b>    | No                                 | POCUS accuracy and prognosis |

| Study                              | STONE Score Specifically Studied? | Primary Focus                             |
|------------------------------------|-----------------------------------|-------------------------------------------|
| <b>2018</b>                        |                                   |                                           |
| <b>C. Moore et al., 2019a</b>      | No                                | Imaging consensus                         |
| <b>S. Guercio et al., 2011</b>     | No                                | Emergency vs delayed ureteroscopy         |
| <b>B. H. Chi et al., 2018</b>      | No                                | Low-dose CT with iterative reconstruction |
| <b>P. Dahm et al., 2022</b>        | Yes - analyzed scoring system     | Diagnostic accuracy meta-analysis         |
| <b>Rajesh Bhayana et al., 2020</b> | No                                | CT workflow optimization                  |
| <b>Y. Tung Chen et al., 2021</b>   | No                                | Fast-track pathway                        |
| <b>C. Moore et al., 2019b</b>      | No                                | Imaging guidelines                        |
| <b>I. Metzler et al., 2017</b>     | No                                | Imaging modality and surgical management  |
| <b>Y. Park et al., 2016</b>        | No                                | Bedside ultrasound effect on ED stay      |
| <b>Tony T Chen et al., 2015</b>    | No                                | Radiation exposure in nephrolithiasis     |
| <b>M. Gottlieb et</b>              | No                                | POCUS effectiveness                       |

| Study                                  | STONE Score<br>Specifically Studied? | Primary Focus                          |
|----------------------------------------|--------------------------------------|----------------------------------------|
| al., 2019                              |                                      |                                        |
| Mei-Yi Ong<br>et al., 2022             | No                                   | Contrast-induced nephropathy           |
| Suad S. Al-<br>Bulushi et al.,<br>2015 | No                                   | Ultrasound predictive value            |
| T. Begaz et<br>al., 2017               | No                                   | Waiting room diagnostic testing        |
| A. Shemesh et<br>al., 2022             | No                                   | Urological consultation outcomes       |
| P. Massaro et<br>al., 2017             | No                                   | CT obstruction as predictor            |
| P. Sen et al.,<br>2022                 | No                                   | COVID-19 impact                        |
| A. Meltzer et<br>al., 2017             | No                                   | Tamsulosin for stone passage           |
| H. Alkadhi et<br>al., 2018             | Referenced                           | Reduced-dose CT underutilization       |
| C. Wiysonge<br>et al., 2014            | No                                   | Low-dose CT discussion                 |
| Ian Berger et<br>al., 2023             | No                                   | Work productivity                      |
| Hasan                                  | No                                   | Radiologist interpretation differences |

| Study                         | STONE Score<br>Specifically Studied? | Primary Focus                   |
|-------------------------------|--------------------------------------|---------------------------------|
| Yeşilağaç et al., 2020        |                                      |                                 |
| Esra Akçiçek et al., 2025     | No                                   | Repeat CT utility               |
| Zachary A Valley et al., 2020 | No                                   | Acute care urology model        |
| C. Dunne et al., 2022         | No                                   | CT reduction interventions      |
| F. Rodger et al., 2018        | No                                   | Low/ultra-low dose CT accuracy  |
| H. Xiang et al., 2017         | No                                   | Low-dose CT diagnostic accuracy |
| D. Assimos et al., 2016       | No                                   | Surgical management guidelines  |
| Ralph C. Wang et al., 2022    | No                                   | Ultrasound-first CDS tool       |
| S. Kim et al., 2019           | No                                   | Protocolized POCUS              |
| Monica Tung et al., 2017      | No                                   | Imaging overuse factors         |
| Jennifer L                    | No                                   | Pain and surgical intervention  |

| Study                                | STONE Score<br>Specifically Studied? | Primary Focus                         |
|--------------------------------------|--------------------------------------|---------------------------------------|
| Portis et al.,<br>2018               |                                      |                                       |
| S. Pendem et<br>al., 2020            | No                                   | Low-dose CT effectiveness             |
| N. Shivakumar<br>et al., 2022        | No                                   | COVID-19 impact                       |
| T. Niemann<br>et al., 2008           | No                                   | Low-dose CT diagnostic performance    |
| Trevor A.<br>McGrath et<br>al., 2020 | No                                   | Dual-energy CT for uric acid stones   |
| Joseph Basile<br>et al., 2018        | No                                   | Oral contrast elimination             |
| K. Shah et<br>al., 2014              | No                                   | Total-body CT in trauma               |
| L. Tzelves et<br>al., 2024           | No                                   | Ultrasound follow-up                  |
| S. Yallappa et<br>al., 2018          | No                                   | Natural history of ureteral stones    |
| C. Moore et<br>al., 2021             | No                                   | Radiation dose reduction intervention |
| S. Kravchick<br>et al., 2005         | No                                   | Emergency ESWL                        |

| Study                            | STONE Score<br>Specifically Studied? | Primary Focus                    |
|----------------------------------|--------------------------------------|----------------------------------|
| M. Assmus et al., 2017           | No                                   | Acute stone clinic effect        |
| Dima Raskolnikov et al., 2020    | No                                   | ED discharge pathway             |
| Alan Shan et al., 2020           | No                                   | Race/ethnicity and imaging       |
| G. Innes et al., 2019            | No                                   | Early intervention outcomes      |
| B. Tombal et al., 2005           | No                                   | Emergency ESWL                   |
| Y. Nuswantoro et al., 2024       | No                                   | Radiologic imaging modalities    |
| Kirsten Foell et al., 2013       | No                                   | Baseline KUB utility             |
| Prakashini Koteswar et al., 2016 | No                                   | Low-dose CT with tube modulation |
| N. Kinnear et al., 2020          | No                                   | Emergency urology models         |
| R. Gohil et al., 2011            | No                                   | Early CT in acute abdomen        |
| Y. Matani et                     | No                                   | Emergency ureteroscopy           |

| Study                                 | STONE Score<br>Specifically Studied? | Primary Focus                   |
|---------------------------------------|--------------------------------------|---------------------------------|
| al., 2013                             |                                      |                                 |
| Ramin<br>Haghighi et<br>al., 2025     | No                                   | Radiological modalities review  |
| Chen-Chih<br>huang et al.,<br>2008    | No                                   | Renal parenchymal density       |
| S. Tartari et<br>al., 2010            | No                                   | Low-dose CT by body size        |
| W. F. Lee et<br>al., 2024             | No                                   | POCUS with limited training     |
| M. Moran et<br>al., 2013              | No                                   | Emergency ESWL outcomes         |
| Tiina T.<br>Lehtimäki et<br>al., 2013 | No                                   | Routine CT vs selective imaging |
| K. Lindqvist<br>et al., 2006          | No                                   | Immediate vs deferred imaging   |
| M. Gautam et<br>al., 2020             | No                                   | Low-dose CT in obese patients   |
| Jesse Spooner<br>et al., 2023         | No                                   | COVID-19 impact on stone care   |
| M. Ordon et                           | No                                   | Early intervention timing       |

| Study                  | STONE Score Specifically Studied? | Primary Focus                           |
|------------------------|-----------------------------------|-----------------------------------------|
| al., 2023              |                                   |                                         |
| R. Sehgal et al., 2021 | No                                | Primary ureteroscopy cost-effectiveness |
| O. Claros et al., 2012 | No                                | Physician practice patterns             |
| Xiao Wang et al., 2024 | No                                | Acupuncture for pain relief             |

The table above reveals that only 4 studies directly examined the STONE score: C. Moore et al. (2016) implemented STONE score-guided reduced-dose CT protocols ; H. Mirfazaelian et al. (2020) conducted a systematic review pooling STONE score performance data ; P. Dahm et al. (2022) analyzed the STONE scoring system within a broader systematic review ; and E. Schoenfeld et al. (2021) incorporated the STONE score into a shared decision-making tool . The remaining studies examined related topics including alternative imaging strategies, low-dose CT protocols, and clinical decision support tools that do not specifically incorporate the STONE score.

## STONE Score Performance and Risk Stratification

### Diagnostic Performance of the STONE Score

The STONE score is a clinical prediction rule calculated using five elements: sex, timing, origin, nausea, and erythrocytes . The score ranges from 0-13 and stratifies patients into low, moderate, and high-risk categories for urolithiasis .

A systematic review and meta-analysis pooling data from eight studies on the STONE rule demonstrated that the prevalence of urolithiasis varied substantially by risk

category: 12% (95% CI 9%-15%) in the low-risk group, 53% (95% CI 43%-62%) in the moderate-risk group, and 83% (95% CI 75%-91%) in the high-risk group . In patients with high STONE scores, the prevalence of clinically important alternative diagnoses was only 1% (95% CI 0%-2%), and 11% (95% CI 8%-13%) of patients required intervention . The STONE score with a threshold of  $\geq 6$  demonstrated a sensitivity of 0.94 and specificity of 0.43, with the ability to rule out stones accurately when the score was less than 6 (likelihood ratio of 0.15, 95% CI 0.10-0.22) .

However, the systematic review noted high heterogeneity among included studies, raising concerns about the score's applicability across different clinical settings . The authors concluded that while the STONE scoring system is useful for estimating urolithiasis prevalence, this heterogeneity makes it unsuitable for direct clinical application without further research .

## **Effects of STONE Score-Guided Imaging on CT Usage**

### **Direct STONE Score Implementation Studies**

The most direct evidence for STONE score-guided CT reduction comes from a prospective single-center study at an urban academic emergency department . In this study, all patients with high STONE scores (10-13) underwent reduced-dose CT, while those with moderate scores (6-9) underwent either reduced-dose or standard CT based on clinician discretion . The intervention achieved an average dose reduction of 88.2%, with dose-length product decreasing from 857 mGy·cm for standard-dose CT to 101 mGy·cm for reduced-dose CT . Among 108 patients who underwent reduced-dose CT alone with complete follow-up, the protocol demonstrated 100% sensitivity (95% CI 86.7%-100%) for detecting stones requiring urologic intervention .

A second study incorporating the STONE score into a decision aid for shared decision-making hypothesized a reduction in CT scan usage from 80% to 60% . The

decision aid provided clinicians with documentation clarifying the STONE score and its implications, delivered through paper-based materials following a one-hour lecture and 3-minute refresher training . This adaptive randomized controlled trial measured CT scan proportion during ED visits and within 60 days as primary outcomes .

### CT Usage Outcomes Across Interventions

| Study                                | Intervention Type                         | CT Metric            | Baseline      | Post-intervention   | Reduction     | Statistical Significance      |
|--------------------------------------|-------------------------------------------|----------------------|---------------|---------------------|---------------|-------------------------------|
| <b>C. Moore et al., 2016</b>         | STONE score + reduced-dose CT             | Dose-length product  | 857 mGy·cm    | 101 mGy·cm          | 88.2%         | 95% CI 86.7%-100% sensitivity |
| <b>R. Smith-Bindman et al., 2014</b> | Ultrasound-first                          | Cumulative radiation | Higher        | Significantly lower | Not specified | P<0.001                       |
| <b>B. H. Chi et al., 2018</b>        | Low-dose CT with iterative reconstruction | Effective dose       | 6.52 mSv      | 1.63 mSv            | 75.2%         | P<0.001                       |
| <b>Ralph C. Wang et al., 2022</b>    | Ultrasound-first CDS tool                 | CT receipt rate      | 94.4%         | 86.7%               | 7.7%          | ARD -7.7% (-14.8 to -0.6%)    |
| <b>C. Moore et al., 2021</b>         | Dose optimization intervention            | Dose-length product  | Baseline 2015 | 16% reduction       | 16%           | P<0.05                        |

| Study                 | Intervention Type        | CT Metric          | Baseline | Post-intervention | Reduction | Statistical Significance       |
|-----------------------|--------------------------|--------------------|----------|-------------------|-----------|--------------------------------|
| C. Moore et al., 2015 | Reduced-dose CT protocol | Size-specific dose | 21.7 mGy | 3.4 mGy           | 84%       | 95% CI 82.3%-95.0% sensitivity |

The table demonstrates that various interventions can substantially reduce radiation exposure or CT utilization, though the STONE score-specific interventions are limited to dose reduction within CT-receiving populations rather than overall CT avoidance.

### Multispecialty Consensus on Imaging Selection

A systematic review with modified Delphi process achieved multispecialty consensus across 29 clinical scenarios for suspected renal colic . The consensus recommended CT in only 7 scenarios (24%), ultrasound in 9 scenarios (31%), and no further imaging in 12 scenarios (45%) . Agreement was rated as perfect in 15 scenarios (52%), excellent in 8 (28%), good in 3 (10%), and moderate in 3 (10%) . This consensus supports the concept that many patients with suspected nephrolithiasis may not require CT imaging, aligning with the theoretical basis for STONE score-guided imaging reduction.

### Alternative Imaging Strategies

#### Point-of-Care Ultrasound Performance

Point-of-care ultrasound (POCUS) represents the primary alternative to CT for initial evaluation of suspected nephrolithiasis. A systematic review and meta-analysis of five high-quality studies (N=1,773) found pooled sensitivity of 70.2% (95% CI 67.1%-73.2%) and specificity of 75.4% (95% CI 72.5%-78.2%) . The calculated positive and negative likelihood ratios were 2.85 and 0.39, respectively . When moderate or severe hydronephrosis

was present, specificity increased to 94.4% (95% CI 92.7%-95.8%), though sensitivity dropped to 29% .

The landmark STONE trial randomized 2,759 patients to point-of-care ultrasound, radiology-performed ultrasound, or CT . The incidence of high-risk diagnoses with complications was low (0.4%) and did not vary by imaging method . Mean 6-month cumulative radiation exposure was significantly lower in ultrasound groups compared to CT ( $P<0.001$ ) . Serious adverse events occurred in 12.4% of point-of-care ultrasound patients, 10.8% of radiology ultrasound patients, and 11.2% of CT patients ( $P=0.50$ ) .

### **Ultrasound-First Clinical Decision Support**

A randomized trial implementing an ultrasound-first clinical decision support (CDS) tool found that 86.7% of patients in the CDS arm received CT versus 94.4% in usual care, resulting in an absolute risk difference of -7.7% (95% CI -14.8% to -0.6%) . The CDS arm did not result in increased ED revisits, CT scans, or hospitalizations at 7 or 30 days . Mean radiation dose in the CDS arm was 6.8 mSv (95% CI 5.7-7.9 mSv) versus 6.1 mSv (95% CI 5.1-7.1 mSv) in usual care .

A prospective randomized pilot study demonstrated that adding bedside ultrasonography to the diagnostic algorithm significantly reduced ED length of stay from 163.0 minutes to 89.0 minutes ( $P<0.001$ ) without increasing unexpected ED revisits within 7 days . No significant differences were observed in radiation exposure, analgesic requirements, or proportion of alternative diagnoses .

### **Clinical Safety Outcomes**

### **Diagnostic Accuracy of Low-Dose CT Protocols**

Multiple systematic reviews have evaluated low-dose CT performance. A meta-analysis of seven studies (1,061 patients) found pooled sensitivity of 0.966 (95% CI 0.950-

0.978) and specificity of 0.949 (95% CI 0.920-0.970) for low-dose CT protocols . Another systematic review reported sensitivity of 90-97% and specificity of 86-100% for low-dose CT, noting that small stones (<3 mm) may be missed, particularly in obese patients (>30 kg/m<sup>2</sup>) .

Low-dose CT with iterative reconstruction demonstrated 96.97% diagnostic accuracy compared to 98.96% for standard-dose CT (P=0.392), with no significant difference in stone size, location, hydronephrosis detection, or diagnosis of alternative conditions . Ultra-low dose CT showed diagnostic accuracy of 95.5% with sensitivity ranging from 72-99% and specificity from 86-100% .

### **Missed Diagnoses and Adverse Events**

A prospective observational study of reduced-dose CT found one missed diagnosis of a 5-mm kidney stone , with the protocol demonstrating 96.0% (95% CI 80.5%-99.3%) sensitivity for stones requiring intervention within 90 days . The hospital admission rate was 15.9% .

In the STONE trial, diagnostic accuracy did not differ significantly among imaging groups . Return ED visits, hospitalizations, and pain scores (2.0 at 7 days in all groups) were similar across modalities . Related adverse events were infrequent (0.4%) and similar across groups .

A systematic review of CT reduction interventions found that only 44% of studies reported unintended consequences; however, those that did showed no increase in missed diagnoses or patient harm .

## **Implementation Factors and Barriers**

### **Provider and System-Level Barriers**

The primary STONE score implementation study identified several barriers including radiologists' discomfort with reduced-dose CT technique and concerns about diagnostic certainty . Higher-than-expected repeat standard-dose CT scans occurred due to radiologist discomfort, and a "safety valve" allowing standard-dose repeats was incorporated into the protocol . Requests for repeat scans varied substantially by attending physician .

A gap persists between evidence-based recommendations and clinical practice . Despite recommendations for reduced-dose CT and ultrasound-first approaches, CT utilization for suspected nephrolithiasis tripled from 21% to 71% between 1992 and 2009 . An editorial noted that radiologists are not sufficiently using reduced-dose CT for kidney stones despite available evidence .

Several studies identified additional barriers to imaging reduction strategies:

- Lack of clear guidelines emphasizing ultrasound and reduced-dose CT
- Variable comfort levels among clinicians with alternative imaging approaches
- Need for additional CT after initial ultrasound due to limitations in anatomical visualization for surgical planning
- Bedside ultrasound sensitivity limitations for stone size and location
- Limited generalizability across institutions and equipment

### **Facilitating Factors**

Successful implementation was associated with interdisciplinary collaboration between emergency clinicians, physicists, and radiologists . A facility-based intervention providing customized CME modules, personalized consultation, and protocol recommendations achieved

a significant and persistent 16% reduction in mean radiation doses for engaged facilities . Decision aids incorporating the STONE score increased patient knowledge and engagement .

A systematic review found that interventions consistently reducing CT usage included diagnostic pathways, alternative test availability, specialist involvement, and provider feedback . Multidisciplinary-led interventions that provided alternatives to CT imaging were most effective at reducing usage without compromising patient safety . Conversely, family/patient education, clinical decision support tools, or passive guideline dissemination did not consistently reduce usage .

### **Cost and Resource Utilization**

Limited cost data are available specific to STONE score-guided interventions. A cost analysis from the STONE randomized trial found that initial ED visit costs were modestly lower for patients assigned to radiology ultrasound (\$423) compared to CT (\$448,  $P<0.0001$ ) . However, total 7-day costs were not significantly different between groups: \$1,014 for point-of-care ultrasound, \$970 for radiology ultrasound, and \$959 for CT . Hospital admissions contributed over 50% of total costs despite only 11% of patients being admitted . Mean total costs varied substantially by site from \$749 to \$1,239 .

A prospective RCT of protocolized POCUS found significantly lower medical costs in the ultrasound group (\$259) compared to conventional care (\$319,  $P<0.001$ ) . A randomized trial comparing routine abdominal CT to selective imaging found total treatment cost per patient was €1,202 higher in the CT group ( $P=0.002$ ), with imaging costs accounting for approximately 10% of total costs .

A retrospective analysis comparing primary ureteroscopy to ureteral stenting found the overall secondary care cost was greater in the stenting group (£4,485.42 vs £3,536.83) . The average cost per patient related to ER reattendances was significantly higher with stenting (£61.05 vs £20.87,  $P<0.001$ ) .

## Synthesis

### Reconciling Limited Direct Evidence

The evidence directly linking STONE score implementation to reduced CT usage is limited to a single prospective study demonstrating feasibility of STONE score-guided reduced-dose CT protocols with 88.2% radiation dose reduction while maintaining 100% sensitivity for clinically significant stones . The absence of additional direct implementation studies represents a significant gap between the theoretical utility of the STONE score for risk stratification and its practical application to reduce unnecessary imaging.

### Explaining Heterogeneity in Risk Stratification Performance

The high heterogeneity observed in STONE score meta-analyses (with urolithiasis prevalence ranging from 12% to 83% across risk categories) likely reflects differences in patient populations, clinical settings, and reference standards . The score demonstrates stronger performance for ruling out stones (LR- 0.15 at threshold <6) than for ruling them in, suggesting its primary utility may be in identifying low-risk patients who can avoid CT rather than confirming high-risk patients who require imaging .

### Alternative Pathways to CT Reduction

The broader literature suggests multiple effective pathways to reduce CT utilization that do not require formal STONE score calculation:

1. **Ultrasound-first protocols** : These achieve 7.7% absolute reductions in CT usage without increasing adverse events , though most patients (78%) still receive CT before surgical intervention .
2. **Low-dose CT protocols** : These maintain diagnostic accuracy (sensitivity 90-97%, specificity 86-100%) while reducing radiation exposure by 75-88% , though they do not reduce overall CT ordering.

3. **Multispecialty clinical pathways** : Consensus-based protocols recommend no imaging in 45% of clinical scenarios, representing potential for substantial utilization reduction when implemented .

### **Clinical Context Determining Optimal Strategy**

The choice of imaging strategy should be contextualized by patient characteristics and clinical presentation:

- **Low pre-test probability patients** : The STONE score's ability to identify patients with only 12% stone prevalence suggests these patients may safely undergo ultrasound-first evaluation or clinical observation .
- **High pre-test probability patients** : With 83% stone prevalence and only 1% alternative diagnoses , reduced-dose CT may be appropriate when imaging is needed, though ultrasonography with selective CT remains viable.
- **Patients requiring surgical planning** : Despite initial ultrasound, 78% ultimately receive CT before intervention , suggesting ultrasound-first approaches shift rather than eliminate CT utilization in this population.
- **Obese patients** : Low-dose CT may miss small stones (<3 mm) but still identifies most alternative diagnoses in patients with BMI >30 kg/m<sup>2</sup> .

### **Implementation Requirements**

Successful CT reduction requires system-level changes including interdisciplinary collaboration , customized education with personalized consultation , and integration of alternatives into workflow rather than passive guideline dissemination . The persistent gap between evidence and practice—with CT utilization tripling despite available alternatives — underscores that clinical prediction tools alone are insufficient without accompanying implementation support.

The STONE score represents one component of a comprehensive approach to judicious imaging in suspected nephrolithiasis. Its value lies primarily in identifying low-risk patients who may avoid imaging entirely, rather than directing reduced-dose protocols for moderate-to-high risk patients who will likely receive CT regardless of initial risk stratification.

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## DISCUSSION

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This systematic review reveals a complex landscape where the theoretical potential of the STONE score for reducing CT utilization is not strongly borne out by direct evidence. The discussion reconciles these findings, explores the score's role within broader strategies, and examines critical implementation factors.

### Reconciling Limited Direct Evidence for CT Utilization Reduction

A central finding is the stark scarcity of studies directly evaluating STONE score implementation with CT ordering rates as a primary outcome. Among 80 sources, only four specifically studied the STONE score, and only one (Moore et al., 2016) prospectively implemented it to guide imaging, focusing on *dose reduction* rather than *scan avoidance*. This study achieved an impressive 88.2% reduction in radiation dose (dose-length product) by using reduced-dose CT for high-STONE-score patients, but it did not decrease the proportion of patients receiving a CT scan. This highlights a critical distinction: the STONE score has been primarily applied to mitigate radiation exposure *within* a population already selected for CT, not to reduce the overall number of CT scans performed. The hypothesis that STONE score implementation reduces CT utilization remains largely untested in robust, controlled studies.

### The STONE Score as a Risk Stratification Tool: Strengths and Limitations

The score's diagnostic performance underpins its utility. Meta-analysis indicates it effectively stratifies risk, with a low-risk group having only a 12% prevalence of urolithiasis and a

high-risk group having an 83% prevalence (Mirfazaelian et al., 2020). Its high negative likelihood ratio (LR- 0.15 for scores <6) suggests it is particularly useful for *ruling out* stones, supporting its potential to identify patients who may not need immediate imaging. However, high statistical heterogeneity across validation studies limits its generalizability and suggests that its predictive value may vary significantly by patient population and clinical setting (Mirfazaelian et al., 2020). This heterogeneity may explain clinician reluctance to rely on it solely to forgo imaging.

### **Alternative and Complementary Pathways to CT Reduction**

The broader literature identifies several effective strategies that either circumvent or incorporate elements of risk stratification, often without formal STONE score calculation:

1. **Ultrasound-First Protocols:** Strong evidence supports this approach. The landmark STONE trial found no significant difference in serious adverse events between ultrasound and CT groups, while significantly reducing radiation exposure (Smith-Bindman et al., 2014). Subsequent implementation trials, such as the ultrasound-first clinical decision support (CDS) tool studied by Ralph C. Wang et al. (2022), demonstrated a 7.7% absolute reduction in CT receipt. However, a key limitation is that many patients, especially those needing surgical planning, still undergo CT after initial ultrasound, indicating that this strategy often shifts rather than eliminates CT use (Metzler et al., 2017).
2. **Low-Dose and Reduced-Dose CT Protocols:** When CT is deemed necessary, dose reduction is a highly effective and evidence-based strategy. Multiple systematic reviews confirm that low-dose CT maintains high diagnostic accuracy (sensitivity 90-97%, specificity 86-100%) for stone detection (Xiang et al., 2017; Rodger et al., 2018). Studies like Chi et al. (2018) have shown dose reductions of 75% using iterative reconstruction techniques. This approach addresses radiation concerns without challenging the deeply ingrained practice pattern of obtaining a CT scan.

3. **Multispecialty Consensus and Clinical Pathways:** The consensus work by Moore et al. (2019) is pivotal, suggesting that based on clinical scenario, 45% of patients may require no imaging at all. This aligns with the STONE score's identification of low-risk patients but provides a broader, scenario-based framework that may be more palatable to clinicians than a numerical score.

### **Contextualizing the STONE Score within a Clinical Framework**

The choice of imaging strategy must be contextual. For the **low pre-test probability patient** (identified by a low STONE score), observation or ultrasound is likely sufficient and safe (Smith-Bindman et al., 2014; Al-Bulushi et al., 2015). For the **high pre-test probability patient** (high STONE score), the question shifts from *whether* to image to *how* to image. Here, reduced-dose CT is a rational choice, though point-of-care ultrasound can still serve as a rapid initial bed-side test. For **patients requiring potential surgical intervention**, early CT may be unavoidable for precise anatomic planning, making strategies like "ultrasound-first with selective CT" the most realistic pathway to modest overall reduction (Metzler et al., 2017). Patient factors also matter; for example, low-dose CT may miss small stones in **obese patients**, slightly altering the risk-benefit calculation (Gautam et al., 2020).

### **Implementation Barriers: The Gap Between Evidence and Practice**

A significant theme is the persistent gap between evidence-based recommendations and clinical practice. Despite strong data for ultrasound-first and low-dose CT, utilization of standard-dose CT has risen dramatically (Alkadhi & Saltybaeva, 2018). Key barriers identified include:

- **Radiologist Discomfort:** A major impediment to reduced-dose CT is radiologist concern over diagnostic certainty and image noise, leading to "safety-valve" repeat standard-dose scans that undermine protocol effectiveness (Moore et al., 2016).

- **Clinician Habits and Comfort:** Emergency physicians may lack training or confidence in point-of-care ultrasound for stones and may perceive CT as faster, more definitive, and medicolegally safer (Gottlieb et al., 2019; Tung et al., 2017).
- **Systemic and Workflow Issues:** Lack of integrated decision support, inadequate feedback mechanisms, and workflow inertia prevent the adoption of new pathways (Dunne et al., 2022).

### Facilitators for Success

Successful interventions share common features: they are **multifaceted** and **system-oriented**. Effective CT reduction is rarely achieved by simply introducing a prediction rule. Instead, it requires interdisciplinary collaboration (emergency medicine, radiology, urology), embedded clinical decision support within the electronic health record, active education with audit/feedback, and ensuring ready availability of alternative imaging like ultrasound (Moore et al., 2021; Dunne et al., 2022). The STONE score may be most effective when embedded as one component within such a comprehensive clinical pathway or decision aid, as pilied by Schoenfeld et al. (2021), rather than as a standalone tool.

### Safety and Economic Considerations

Importantly, strategies to reduce or optimize CT do not appear to compromise patient safety. Studies consistently show no increase in missed serious diagnoses, return visits, or hospital admissions with ultrasound-first or low-dose CT approaches (Smith-Bindman et al., 2014; Moore et al., 2015). Economically, while imaging costs are a factor, the dominant driver of total cost is hospital admission (Melnikow et al., 2016). Therefore, interventions that safely avoid admission or facilitate outpatient management, potentially aided by risk stratification and timely urology consultation (Shemesh et al., 2022), may have greater economic impact than focusing solely on imaging costs.

## Summary

The STONE score is a clinically useful risk-stratification tool with a particular strength in identifying low-risk patients. However, direct evidence that its implementation reduces CT *scan rates* is minimal. Its real-world value is likely as an element of a broader, multimodal strategy to promote judicious imaging. This strategy should prioritize: 1) **Ultrasound as the initial imaging test** for most patients, 2) **Use of reduced-dose CT protocols** when CT is necessary, and 3) **Implementation of clinical pathways** that incorporate risk assessment (like the STONE score) into integrated decision support within a supportive system culture. Future research should focus on implementing and evaluating such bundled interventions rather than isolating the effect of the prediction score alone.

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## CONCLUSION AND RECOMMENDATIONS

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### Conclusion

This systematic review indicates that the association between STONE score implementation and a reduction in CT scan *utilization* in the emergency department is not strongly supported by direct evidence. The score is a valid diagnostic tool for stratifying patient risk of urolithiasis, with particular utility in identifying a low-risk cohort suitable for observation or ultrasound. However, in practice, its application has been more closely linked to reducing radiation *dose* (via guided reduced-dose CT) rather than reducing the overall *frequency* of CT ordering. Effective reduction of unnecessary CT imaging for suspected renal colic relies less on any single prediction rule and more on the implementation of multifaceted strategies, including ultrasound-first protocols, low-dose CT technology, and embedded clinical decision pathways supported by interdisciplinary collaboration.

### Recommendations

1. **For Clinical Practice:** Emergency departments should adopt **ultrasound as the first-line imaging modality** for stable patients with suspected uncomplicated renal colic. For patients

where CT is clinically indicated, **reduced-dose or low-dose CT protocols should be the standard**. The STONE score can be used informally or formally to reinforce decision-making, especially to justify deferring imaging in low-risk patients.

2. **For System Implementation:** Hospitals should invest in **integrated clinical decision support systems** that incorporate risk stratification (like the STONE score) into order-entry panels, guiding providers toward ultrasound or low-dose CT based on patient factors. This must be coupled with **interdisciplinary protocols** developed jointly by Emergency Medicine, Radiology, and Urology, and supported by **training and audit/feedback** for both physicians and radiologists to overcome comfort barriers.
3. **For Future Research:** High-quality, multicenter intervention studies are needed to evaluate the impact of **bundled strategies** that combine the STONE score with ultrasound-first pathways and dose optimization protocols on the hard endpoint of CT utilization rate. Research should also explore the **cost-effectiveness** of such comprehensive approaches and investigate methods to improve radiologist acceptance and confidence in reduced-dose CT interpretations.

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