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# ACCURACY OF DUAL-ENERGY COMPUTED TOMOGRAPHY FOR DETECTING URIC ACID URINARY CALCULI VERSUS CONVENTIONAL COMPUTED TOMOGRAPHY

# ACURÁCIA DA TOMOGRAFIA COMPUTADORIZADA DE DUPLA ENERGIA NA DETECÇÃO DE CÁLCULOS URINÁRIOS DE ÁCIDO ÚRICO VERSUS TOMOGRAFIA COMPUTADORIZADA CONVENCIONAL

# PRECISIÓN DE LA TOMOGRAFÍA COMPUTARIZADA DE DOBLE ENERGÍA EN LA DETECCIÓN DE CÁLCULOS URINARIOS DE ÁCIDO ÚRICO VERSUS TOMOGRAFÍA COMPUTARIZADA CONVENCIONAL

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## ABSTRACT

Noncontrast computed tomography is highly effective for detecting urinary calculi, but conventional single-energy attenuation values overlap among compositions and cannot consistently identify uric acid. Dual-energy computed tomography exploits the energy-dependent attenuation of materials to classify calculi as uric-acid or non-uric-acid, potentially enabling immediate selection of urinary alkalinization and avoidance of unnecessary intervention. This structured diagnostic-accuracy review compares dual-energy and conventional computed tomography, emphasizing chemical stone analysis as the preferred reference standard, direct comparative evidence, low-dose performance, and clinically important failure modes. Early phantom and ex vivo investigations demonstrated near-complete separation of uric-acid from non-uric-acid stones under favorable conditions. Prospective and retrospective in vivo studies subsequently reported high specificity, with failures concentrated in very small stones, large body habitus, noisy reduced-dose acquisitions, mixed composition, and incompletely mapped calculi. A 2020 systematic review and bivariate meta-analysis of 21 studies found mean sensitivity of 0.88 and specificity of 0.98 for uric-acid-dominant stones; performance for any uric-acid-containing stone was lower, with sensitivity of 0.82 and specificity of 0.97. Direct studies favored dual-energy over conventional computed tomography: one prospective in vitro comparison correctly classified 74% versus 52% of stones overall and 93% versus 40% of non-uric-acid stones in the binary

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uric-acid distinction, while an in vivo comparison reported 90% versus 52% correct composition assessment. Conventional computed tomography can perform well when mean, maximum, distributional attenuation features and urine pH are combined, but thresholds are scanner-, protocol-, size-, and reconstruction-dependent; some modern single-energy algorithms have been validated against vendor dual-energy classification rather than chemical analysis, which limits claims of equivalence. Radiation exposure with contemporary low-dose dual-energy protocols can approach routine stone computed tomography, although dose reduction increases unclassified small calculi. Dual-energy computed tomography is therefore the best-established noninvasive method for uric-acid composition assessment when the result will change management, but it should complement rather than replace retrieved-stone analysis whenever material is available.

**Keywords:** Dual-energy Computed Tomography. Urinary Calculi. Uric Acid. Urolithiasis. Diagnostic Accuracy. Hounsfield Units. Stone Composition.

## RESUMO

A tomografia computadorizada sem contraste é altamente eficaz na detecção de cálculos urinários, mas os valores de atenuação de energia única convencional se sobrepõem entre composições e não conseguem identificar consistentemente ácido úrico. A tomografia computadorizada de dupla energia explora a atenuação dependente de energia dos materiais para classificar cálculos como ácido úrico ou não ácido úrico, potencialmente permitindo seleção imediata de alcalinização urinária e evitando intervenção desnecessária. Esta revisão estruturada de acurácia diagnóstica compara tomografia computadorizada de dupla energia e convencional, enfatizando análise química de cálculos como padrão de referência preferido, evidência comparativa direta, desempenho em baixa dose e modos de falha clinicamente importantes. Investigações iniciais em fantomas e ex vivo demonstraram separação quase completa de cálculos de ácido úrico de cálculos não-ácido úrico sob condições favoráveis. Estudos prospectivos e retrospectivos in vivo subsequentes relataram alta especificidade, com falhas concentradas em cálculos muito pequenos, grande habitus corporal, aquisições em dose reduzida ruidosas, composição mista e cálculos incompletamente mapeados. Uma revisão sistemática de 2020 e meta-análise bivariada de 21 estudos encontraram sensibilidade média de 0,88 e especificidade de 0,98 para cálculos dominantes de ácido úrico; o desempenho para qualquer cálculo contendo ácido úrico foi menor, com sensibilidade de 0,82 e especificidade de 0,97. Estudos diretos favoreceram tomografia computadorizada de dupla energia sobre convencional: uma comparação prospectiva in vitro classificou corretamente 74% versus 52% de cálculos em geral e 93% versus 40% de cálculos não-ácido úrico na distinção binária de ácido úrico, enquanto uma comparação in vivo relatou 90% versus 52% de avaliação correta de composição. A tomografia computadorizada convencional pode ter bom desempenho quando características de atenuação média, máxima, distribucional e pH urinário são combinadas, mas os limiares são dependentes de scanner, protocolo, tamanho e reconstrução; alguns algoritmos modernos de energia única foram validados contra classificação dual-energia do fornecedor em vez de análise química, o que limita as alegações de equivalência. A exposição à radiação com protocolos contemporâneos de baixa dose de dupla energia pode se aproximar da tomografia computadorizada rotineira de cálculos, embora a redução de dose aumente cálculos pequenos não classificados. A tomografia computadorizada de dupla energia é portanto o método não invasivo mais bem estabelecido para avaliação de composição de ácido úrico quando o resultado mudará o manejo, mas deve complementar e não substituir a análise de cálculos recuperados sempre que o material estiver disponível.

**Palavras-chave:** Tomografia Computadorizada de Dupla Energia. Cálculos Urinários. Ácido Úrico. Urolitíase. Acurácia Diagnóstica. Unidades Hounsfield. Composição de Cálculos.

**RESUMEN**

La tomografía computarizada sin contraste es altamente efectiva para detectar cálculos urinarios, pero los valores de atenuación convencionales de energía única se superponen entre composiciones y no pueden identificar consistentemente el ácido úrico. La tomografía computarizada de doble energía aprovecha la atenuación dependiente de la energía de los materiales para clasificar los cálculos como ácido úrico o no ácido úrico, lo que potencialmente permite la selección inmediata de alcalinización urinaria y evita intervenciones innecesarias. Esta revisión estructurada de precisión diagnóstica compara la tomografía computarizada de doble energía y convencional, enfatizando el análisis químico de cálculos como el estándar de referencia preferido, la evidencia comparativa directa, el rendimiento de dosis baja y los modos de fallo clínicamente importantes. Las investigaciones tempranas con fantomas y ex vivo demostraron una separación casi completa de los cálculos de ácido úrico de los cálculos no ácido úrico en condiciones favorables. Los estudios prospectivos y retrospectivos in vivo posteriormente reportaron alta especificidad, con fallas concentradas en cálculos muy pequeños, contextura corporal grande, adquisiciones de dosis reducida ruidosas, composición mixta y cálculos incompletamente mapeados. Una revisión sistemática y un metaanálisis bivariado de 2020 de 21 estudios encontraron una sensibilidad media de 0,88 y especificidad de 0,98 para cálculos dominantes de ácido úrico; el rendimiento para cualquier cálculo que contenga ácido úrico fue menor, con sensibilidad de 0,82 y especificidad de 0,97. Los estudios directos favorecieron la tomografía computarizada de doble energía sobre la convencional: una comparación prospectiva in vitro clasificó correctamente el 74% versus 52% de los cálculos en general y el 93% versus 40% de los cálculos no ácido úrico en la distinción binaria de ácido úrico, mientras que una comparación in vivo reportó 90% versus 52% de evaluación correcta de la composición. La tomografía computarizada convencional puede funcionar bien cuando se combinan características de atenuación media, máxima y distribucional y el pH de la orina, pero los umbrales dependen del escáner, protocolo, tamaño y reconstrucción; algunos algoritmos modernos de energía única han sido validados contra la clasificación de doble energía del proveedor en lugar del análisis químico, lo que limita las afirmaciones de equivalencia. La exposición a radiación con protocolos contemporáneos de doble energía de dosis baja puede aproximarse a la tomografía computarizada de cálculos de rutina, aunque la reducción de dosis aumenta los cálculos pequeños sin clasificar. La tomografía computarizada de doble energía es, por lo tanto, el método no invasivo mejor establecido para la evaluación de la composición de ácido úrico cuando el resultado cambiará el manejo, pero debe complementar en lugar de reemplazar el análisis de cálculos recuperados siempre que haya material disponible.

**Palabras clave:** Tomografía Computarizada de Doble Energía. Cálculos Urinarios. Ácido Úrico. Urolitiasis. Precisión Diagnóstica. Unidades Hounsfield. Composición de Cálculos.

## 1 INTRODUCTION

Uric-acid calculi represent a clinically important minority of urinary stones, with prevalence varying according to age, obesity, diabetes, metabolic syndrome, diet, geography, and the population undergoing stone analysis.[1] Their recognition matters because urinary alkalinization can dissolve pure or uric-acid-dominant stones and may avert ureteroscopy, shock-wave lithotripsy, or percutaneous intervention in appropriately selected patients.[2–4]

Noncontrast computed tomography is the reference imaging examination for suspected renal colic because it detects radiopaque and radiolucent calculi, localizes obstruction, measures stone size, and identifies alternative diagnoses.[2] The same examination provides attenuation in Hounsfield units, but conventional single-energy values overlap across uric acid, cystine, struvite, calcium oxalate, and mixed stones because measurement depends on composition, stone size, region-of-interest placement, tube potential, reconstruction, noise, and partial-volume effects.[5–9]

Combining conventional computed-tomography attenuation with urine pH improves prediction because uric-acid crystallization is favored by persistently acidic urine.[6] Distributional image features, including maximum attenuation, standard deviation, kurtosis, and spatial pixel patterns, further increase discrimination in selected cohorts.[7–10] These methods remain probabilistic and threshold dependent, and their apparent accuracy may fall when applied to small, heterogeneous, or mixed-composition calculi outside the development setting.[7–10]

Dual-energy computed tomography acquires or reconstructs attenuation information at two energy spectra and uses the difference in material behavior to separate uric-acid from non-uric-acid stones.[11–16] Early phantom and ex vivo studies reported very high accuracy, while subsequent in vivo investigations compared the color-coded or ratio-based classification with infrared spectroscopy or x-ray diffraction.[11–16] Direct comparative studies generally found dual-energy classification more accurate than conventional 120-kV attenuation for the binary uric-acid distinction.[17,19]

Diagnostic performance is nevertheless conditional rather than absolute.[18,20,21] Small calculi may not contain enough voxels for stable two-energy measurement, reduced radiation dose increases noise, and large body habitus can degrade spectral separation.[11,16,18,20] Mixed stones create a reference-standard problem because a test optimized for uric-acid-dominant calculi is not answering the same question as a test intended to detect any uric-acid component.[15,22,23]

Published meta-analyses support high dual-energy specificity, but pooled estimates combine scanner generations, acquisition modes, postprocessing thresholds, reference

standards, and target definitions.[22,23] Comparative test-accuracy interpretation requires explicit attention to paired versus unpaired design, verification, patient spectrum, and the clinical consequences of false-positive and false-negative classifications.[25–28] The relevant question is not whether dual-energy computed tomography produces a color overlay, but whether it improves composition diagnosis over conventional computed tomography at an acceptable dose and changes a management decision.[2–4,17,19]

## 2 OBJECTIVE

To compare the diagnostic accuracy of dual-energy computed tomography with conventional single-energy computed tomography for identifying uric-acid urinary calculi, critically examining reference standards, direct comparative evidence, low-dose performance, technical limitations, and implications for chemolysis and procedural planning.

## 3 METHODS

A structured review of PubMed-indexed diagnostic literature available through October 3, 2026 was performed. Search concepts combined urinary calculus, urolithiasis, kidney stone, ureteral stone, uric acid, composition, dual-energy computed tomography, spectral computed tomography, conventional computed tomography, single-energy computed tomography, Hounsfield unit, sensitivity, specificity, and diagnostic accuracy. Reference lists of diagnostic-accuracy meta-analyses and guideline documents were used to identify pivotal earlier studies.

Eligible evidence included human in vivo diagnostic-accuracy studies, direct paired comparisons between dual-energy and conventional computed tomography, prospective validation of quantitative single-energy methods, and foundational phantom or ex vivo studies that clarified technical failure mechanisms. Retrieved-stone infrared spectroscopy, x-ray diffraction, or another validated compositional analysis was considered the preferred reference standard. Studies using a dual-energy vendor classification as the reference for a new conventional-computed-tomography method were retained but interpreted as agreement studies rather than independent proof of chemical composition.

The synthesis followed PRISMA 2020 and PRISMA diagnostic-test-accuracy principles where applicable, with risk-of-bias considerations based on QUADAS-2 and comparative-test guidance.[24–28] Data were organized by target condition, scanner and acquisition type, stone and patient sample, reference standard, sensitivity, specificity, overall classification, radiation dose, unclassified stones, and technical exclusions. A new meta-analysis was not performed because two high-quality published meta-analyses already

quantified the central binary comparison and the primary studies differed in whether the target was pure, dominant, or any uric-acid-containing calculus.[22],[23]

## 4 RESULTS AND DISCUSSION

### 4.1 CLINICAL TARGET AND REFERENCE STANDARD

The clinically useful target is usually a stone sufficiently dominated by uric acid to justify oral dissolution therapy. This differs from detecting any microscopic uric-acid fraction within a mixed calculus. The 2020 meta-analysis separated a uric-acid-dominant target from a broader uric-acid-containing target and found lower sensitivity for the latter, illustrating that target definition changes measured accuracy.[23]

Chemical analysis of a retrieved stone is the preferred reference because it directly identifies constituent material. Infrared spectroscopy and x-ray diffraction can characterize composition, but sampling a fragment may not fully represent a heterogeneous calculus. A further verification problem arises because only patients who pass or undergo removal of a stone contribute material, while conservatively managed or successfully dissolved stones may lack chemical confirmation.

Dual-energy classification itself should not serve as the independent truth when evaluating whether conventional computed tomography can replace dual energy. The prospective single-energy validation study that reported 98% accuracy for a k-nearest-neighbor method used a vendor dual-energy application as the reference rather than spectroscopy.[10] The study shows close agreement with dual-energy output and potential accessibility, but it cannot establish that both methods were correct when they agreed.

Clinical reference standards can also incorporate response to chemolysis, but reduction in stone size is not perfectly specific for uric acid and depends on adherence, urine pH, duration, obstruction, and mixed composition. For diagnostic-accuracy claims, imaging follow-up after alkalinization is therefore a supportive outcome rather than an equivalent substitute for laboratory analysis.

**Table 1**

*Representative evidence for uric-acid stone characterization with dual-energy computed tomography*

| Study | Design and reference | Performance | Key limitation or contribution |
|---|---|---|---|
| Primak et al., 2007 | 40 human stones in anthropomorphic phantom; micro-CT composition | 100% accuracy in medium/large phantoms; 93–95% in extra-large phantom | Established feasibility and small-stone/noise limitations[11] |
| Stolzmann et al., 2008 | 40 ex vivo stones; crystallographic analysis | All 39 mapped stones correctly classified; one 2-mm uric-acid stone missed | Controlled conditions; mapping failure matters[12] |
| Stolzmann et al., 2010 | Prospective in vivo; 53 chemically analyzed stones | Sensitivity 89%, specificity 98% for uric-acid-containing stones | Only nine uric-acid stones; wide sensitivity uncertainty[14] |
| Hidas et al., 2010 | 27 patients before extraction; x-ray diffraction | 22 of 27 correctly characterized; all six uric-acid stones correct | Mixed and struvite stones reduced granular accuracy[15] |
| Wisenbaugh et al., 2014 | Paired in vitro conventional CT versus DECT; known composition | Overall 52% versus 74%; non-uric-acid recognition 40% versus 93% | Small sample; conventional method used published HU ranges[17] |
| Bonatti et al., 2017 | Paired in vivo 120-kV versus 100/Sn140-kV; infrared spectroscopy | Correct composition 52% versus 90%; DECT uric-acid sensitivity/specificity 1.00/0.94 | Retrospective 30-patient cohort[19] |
| Franken et al., 2018 | Prospective reduced- and standard-dose third-generation DECT | Most labeled stones concordant; reduced dose missed 17 stones, all ≤3 mm | Demonstrated dose–small-stone tradeoff[20] |
| McGrath et al., 2020 | Systematic review; 21 studies, 1,105 patients, 1,442 stones | Uric-acid-dominant sensitivity 0.88, specificity 0.98 | Target definition and scanner heterogeneity remain[23] |
| Euler et al., 2023 | Low-dose DECT; 227 chemically analyzed stones | 225 correct; accuracy 0.99; 82/84 stones ≤3 mm correct | Only fifteen uric-acid stones; modern system performance[21] |

CT, computed tomography; DECT, dual-energy computed tomography; HU, Hounsfield unit. Early controlled studies and later clinical studies answer complementary questions and should not be pooled without accounting for target definition and verification.
Source: Prepared by the authors.

## 4.2 CONVENTIONAL COMPUTED TOMOGRAPHY: STRENGTHS AND LIMITATIONS

Conventional noncontrast computed tomography already answers the urgent questions of stone presence, size, location, obstruction, and alternative diagnosis. Composition assessment is secondary and should not compromise a low-dose stone protocol. Mean attenuation is typically lower for uric-acid than calcium-based calculi, but overlap prevents a single universal threshold.[5,6] Partial volume can depress attenuation in small stones, while beam hardening, reconstruction kernel, and region-of-interest placement alter the estimate.

Clinical context improves conventional-computed-tomography prediction. In 235 patients with analyzed stones, a threshold of 500 Hounsfield units or lower combined with urine pH of 5.5 or lower yielded 86% sensitivity and 98% specificity for uric acid, with positive predictive value rising to 90% for stones larger than 4 mm.[6] The result is practical, but positive predictive value depends on prevalence and the combined rule will not apply when urine is sampled after treatment, infection, fasting, or variable dietary exposure.

Attenuation heterogeneity adds information. A two-center study of 466 patients found that combining mean and standard-deviation Hounsfield units improved likelihood ratios for several stone types, and uric acid was the best-discriminated composition.[7] A later analysis found that mean and maximum attenuation together produced an area under the curve of 0.904 for uric-acid diagnosis.[9] These methods are appealing because they use existing images, but reproducible segmentation and external threshold validation are necessary.

More complex conventional-computed-tomography algorithms can approach dual-energy performance in selected samples. A pixel-mapping method combining attenuation distribution, average attenuation, and size reported 89% sensitivity and 91% specificity for uric acid versus calcium oxalate in stones larger than 4 mm.[8] Restriction to two pure compositions and exclusion of smaller calculi simplify the problem compared with routine practice, which includes cystine, infection, phosphate, and mixed stones.

### 4.3 DUAL-ENERGY PRINCIPLE AND TECHNICAL IMPLEMENTATION

Dual-energy computed tomography measures how attenuation changes between lower and higher photon-energy spectra. Materials with different effective atomic number and density demonstrate different dual-energy ratios, permitting uric-acid separation from calcium-rich stones even when their attenuation at a single tube potential overlaps. Commercial systems typically provide a color-coded classification and may report a dual-energy ratio or material decomposition result.

The acquisition can be implemented with dual-source scanners, rapid tube-potential switching, dual-layer detectors, sequential acquisitions, or other spectral approaches. These technologies differ in temporal registration, spectral separation, field of view, dose allocation, and postprocessing. Performance demonstrated on one implementation cannot be assumed for another without validation, especially when the software threshold is vendor specific.

Stone size, composition homogeneity, and surrounding tissue influence classification. A calculus must occupy enough paired-energy voxels to overcome noise and partial volume. Mixed stones can display spatially heterogeneous colors or be assigned according to the dominant component, while cystine and struvite may overlap with other non-uric-acid groups

when more granular composition is attempted.[12,15,16] The most mature and defensible clinical claim is therefore binary uric-acid versus non-uric-acid classification, not precise identification of every mineral.

### 4.4 FOUNDATIONAL EX VIVO AND EARLY IN VIVO EVIDENCE

The initial anthropomorphic phantom study evaluated forty human stones embedded in porcine kidneys and reported 100% accuracy in medium and large phantoms.[11] In the extra-large phantom, noise produced unclassified or missed small stones, reducing accuracy to 93–95% and uric-acid sensitivity to 88–94% depending on collimation.[11] This study established both the physical feasibility of uric-acid separation and the interaction between body size, noise, and small-stone classification.

An ex vivo evaluation of forty stones found that the software mapped 39, missing one 2-mm uric-acid stone, and correctly classified every mapped stone; manual attenuation plotting correctly classified the missed calculus.[12] Such near-perfect results should not be extrapolated directly to patients because motion, adjacent contrast, body habitus, ureteral location, and dose constraints are absent or controlled.

Early clinical studies confirmed feasibility at practical dose. A low-dose protocol distinguished calcified from noncalcified calculi in all patients with an available chemical analysis, at a measured dose only modestly above the institution's single-energy protocol.[13] In 180 prospectively examined patients, chemical analysis was available in 53; sensitivity and specificity for uric-acid-containing stones were 89% and 98%, although only nine reference stones contained uric acid and the confidence interval for sensitivity was wide.[14]

Single-source dual-energy assessment against x-ray diffraction correctly characterized 22 of 27 patients, including all six uric-acid stones, but mixed and struvite compositions were more difficult.[15] Another low-dose series correctly identified nearly all uric-acid, cystine, and calcium-containing stones at a mean effective dose of 2.7 mSv, while image quality decreased with patient size and the authors cautioned against that protocol in obesity.[16]

**Table 2**

*Dual-energy versus conventional computed tomography for uric-acid composition assessment*

| Domain | Dual-energy CT | Conventional CT | Clinical interpretation |
|---|---|---|---|
| Physical basis | Energy-dependent material attenuation or decomposition | Attenuation magnitude and distribution at one spectrum | Dual energy more directly addresses material identity |
| Typical output | Uric-acid/non-uric-acid color or ratio; possible unclassified result | Mean/max HU, texture or pixel features; probability or threshold | Reports should disclose uncertainty and failure |
| Direct comparative accuracy | 90% correct composition in an in vivo paired study | 52% correct composition in the same study | Early direct evidence favors DECT[19] |
| Meta-analytic evidence | Dominant uric-acid sensitivity 0.88 and specificity 0.98 | No equivalent pooled contemporary paired estimate | DECT has the stronger independent chemical-reference evidence[23] |
| Main strengths | High specificity; rapid actionable classification; robust binary separation | Available from routine noncontrast CT; no special acquisition; retrospective analysis possible | Availability and incremental value should both be considered |
| Main limitations | Small/noisy stones, obesity, mixed stones, vendor dependence, spectral field-of-view limits | Attenuation overlap, protocol dependence, segmentation and threshold variability | Neither method is infallible |
| Best use | When composition will determine chemolysis or avoid intervention | Initial probability estimate or alternative where DECT is unavailable | Retrieved material should still undergo analysis |

The comparison concerns composition characterization, not the basic ability of noncontrast computed tomography to detect a calculus. Modern single-energy algorithms may outperform simple Hounsfield-unit thresholds but require independent validation.
Source: Prepared by the authors.

## 5 DIRECT COMPARISON WITH CONVENTIONAL COMPUTED TOMOGRAPHY

Direct paired comparisons are the most relevant evidence for the question in the title because both tests are applied to the same stones. In a blinded prospective in vitro study, conventional 120-kV attenuation correctly identified 14 of 27 stones overall, compared with 20 of 27 using dual-energy spectral curves.[17] Both methods recognized all twelve uric-acid stones, but conventional computed tomography classified only six of fifteen non-uric-acid stones correctly in the binary comparison, versus fourteen of fifteen for dual energy.[17] The apparent problem was not uric-acid sensitivity alone, but low conventional specificity caused by attenuation overlap.

An in vivo comparison of thirty patients and fifty stones used a low-dose 120-kV acquisition followed by 100/Sn140-kV dual-energy imaging and infrared spectroscopy as the reference.[19] Conventional computed tomography correctly assessed composition in 52%,

versus 90% for dual energy.[19] For uric-acid versus non-uric-acid classification, sensitivity and specificity were 0.94 and 0.72 for conventional imaging and 1.00 and 0.94 for dual energy.[19]

These studies support an accuracy advantage, but both have limitations. The in vitro study included only 27 analyzable stones and used predefined single-energy Hounsfield-unit ranges, while the in vivo study was retrospective, small, and exposed patients to two acquisitions for research comparison.[17,19] Contemporary quantitative single-energy algorithms are more sophisticated than simple attenuation ranges, so the magnitude of superiority over current conventional methods may be smaller than these early comparisons suggest.

A fair contemporary comparison should use the same low-dose dataset whenever technically possible, lock both methods before testing, and apply an independent chemical reference. It should report paired differences in sensitivity and specificity with confidence intervals, unclassified stones, and management consequences. Comparative accuracy alone is insufficient if dual energy requires meaningfully higher dose or is unavailable when the patient presents.

## 6 META-ANALYTIC ESTIMATES AND THEIR INTERPRETATION

The 2016 meta-analysis included nine studies with 609 stones in 415 patients and reported pooled sensitivity of 0.955, specificity of 0.985, and an area under the summary receiver operating characteristic curve of 0.990 for uric-acid versus non-uric-acid calculi.[22] These values demonstrate excellent discrimination but arose from an earlier, relatively small evidence base that included controlled and heterogeneous designs.

The 2020 systematic review used a broader search, QUADAS-2 appraisal, and bivariate random-effects modeling across 21 studies comprising 1,105 patients and 1,442 stones.[23] For uric-acid-dominant stones, fourteen studies yielded mean sensitivity of 0.88 and specificity of 0.98; for any uric-acid-containing stone, thirteen studies yielded sensitivity of 0.82 and specificity of 0.97.[23] The lower sensitivity for the broader target is clinically coherent because small uric-acid components within mixed stones may not determine the voxel-level spectral signal.

High specificity is particularly important before initiating chemolysis because a false uric-acid classification can delay effective procedural treatment for a non-dissolvable obstructing stone. Sensitivity remains important because a false non-uric-acid result denies a patient a potentially noninvasive treatment. The preferred operating point depends on obstruction, infection, renal function, symptom control, stone size, and the feasibility of close follow-up rather than on imaging accuracy alone.

The meta-analysis concluded that dual energy could replace stone analysis in the diagnostic pathway, but retrieved material should still be analyzed when available.[23] Laboratory composition informs prevention, detects mixed mineral, and provides a quality check on imaging. The practical replacement is for pre-treatment composition knowledge when no stone has yet been passed or removed, not for discarding chemical analysis.

## 7 STONE SIZE, BODY HABITUS, NOISE, AND RADIATION DOSE

Small stones are the most consistent technical challenge. They contain fewer full-volume voxels, making classification sensitive to slice thickness, kernel, motion, and segmentation. The foundational studies missed or failed to classify 2–3-mm stones under noisy conditions, and the third-generation reduced-dose study found that a larger proportion of calculi 5 mm or smaller remained unlabeled at reduced dose.[11],[12],[20]

Dose reduction affects material characterization before it necessarily affects stone detection. In a simulated reduction study of 206 stones, performance was minimally affected at 75% of the routine 16-mGy volume computed-tomography dose index for stones at least 10 $mm^3$, but capability declined for smaller volumes and optimal dual-energy-ratio thresholds changed as noise rose.[18] Applying one fixed threshold across dose levels can therefore conceal preventable errors.

Third-generation dual-source systems improve spectral separation using tin filtration, but low dose remains a tradeoff. In 153 patients, reduced-dose imaging achieved a mean volume computed-tomography dose index of 2.67 mGy, yet seventeen stones visible on standard-dose imaging were missed and a greater number of small stones were not labeled.[20] The clinical significance depends on whether the missed calculus is responsible for obstruction and whether its composition would change therapy.

More recent evidence is reassuring. A 2023 study of 227 chemically analyzed stones reported 225 correct dual-energy classifications at a mean effective dose of 2.43 mSv; pooled sensitivity, specificity, and accuracy were 1.00, 0.93, and 0.99, and 82 of 84 stones no larger than 3 mm were correctly classified.[21] Only fifteen stones were uric acid, so sensitivity and specificity labels in the abstract require careful denominator interpretation, but the study demonstrates that excellent small-stone performance is achievable with contemporary equipment.

Body habitus increases photon starvation and noise, particularly in the low-energy dataset. Automatic exposure control, appropriate spectral pairing, iterative or spectral reconstruction, and size-adapted protocols can preserve performance, but a nondiagnostic or unclassified output should be reported rather than forced into a binary color. Dose

comparison should use size-specific dose estimates when possible, not only scanner output averages.

## 8 CAN MODERN CONVENTIONAL COMPUTED TOMOGRAPHY CLOSE THE GAP?

Modern single-energy methods exploit more than mean attenuation. The prospective study of 143 stones combined maximum attenuation with a spatial Laplacian feature and reported 100% sensitivity, 97% specificity, and 98% accuracy against a vendor dual-energy application.[10] A simpler maximum-attenuation model still achieved 94% accuracy in the same dataset.[10] These results show that rich information is present in conventional images and may be valuable where dual energy is unavailable.

The reference-standard limitation is decisive. Agreement with dual-energy classification cannot prove equivalence to chemical analysis when both tests could share an error, particularly for mixed or very small calculi. Models developed from pure uric-acid and calcium-oxalate stones also face spectrum shift when applied to infection, cystine, brushite, or mixed stones.[8]

Conventional computed tomography remains reasonable when the probability is estimated from validated attenuation features, urine pH, clinical phenotype, and close response monitoring. Dual energy is preferable when composition certainty will determine immediate dissolution therapy, when attenuation is equivocal, or when a noninvasive result could avoid intervention. The choice should account for local scanner capability, expertise, dose, and turnaround rather than treating either modality as universally mandatory.

## 9 CLINICAL CONSEQUENCES OF CORRECT AND INCORRECT CLASSIFICATION

Correct identification of a uric-acid-dominant stone can lead directly to alkalinization, most commonly with potassium citrate when not contraindicated, and serial monitoring of urine pH and stone size.[2–4] Contemporary medical-treatment literature reports high rates of dissolution or substantial reduction in selected patients, but success depends on adherence, achieved pH, stone composition, size, obstruction, and duration.[3,4]

A false-positive uric-acid classification may expose the patient to ineffective therapy, electrolyte or gastrointestinal adverse effects, prolonged pain, persistent obstruction, infection risk, and delayed definitive treatment. This consequence is especially important in an obstructed infected system, solitary kidney, worsening renal function, uncontrolled symptoms, or a stone unlikely to pass. Imaging composition must never supersede urgent decompression when clinically indicated.

A false-negative classification may lead to avoidable intervention or loss of a dissolution opportunity. However, procedural choice also depends on stone size, location, anatomy, symptoms, density, skin-to-stone distance, and patient preference. Dual-energy composition is one decision variable, not an isolated command.

Mixed stones require explicit counseling. A stone containing substantial non-uric-acid material may shrink incompletely despite correct detection of a uric-acid component. Failure to change on documented therapeutic urine alkalinization should trigger reassessment of adherence, pH measurement, composition, obstruction, and the need for intervention rather than indefinite continuation.

**Table 3**

*Failure modes, consequences, and mitigation in uric-acid stone classification*

| Failure mode | Potential consequence | Mitigation |
|---|---|---|
| Very small calculus or partial volume | Unclassified or falsely characterized stone | Thin appropriate reconstructions; cautious segmentation; report inability rather than force a label[11,12,18,20] |
| Large body habitus or photon starvation | Noisy low-energy data and reduced spectral separation | Size-adapted protocol, automatic exposure control, optimized reconstruction; disclose limitation[11,16] |
| Aggressive dose reduction | Stone detection preserved but material classification degraded | Validate dose-specific thresholds and monitor unclassified rate[18,20] |
| Mixed composition | Incomplete dissolution despite apparent uric-acid signal | Define dominant versus any-component target; analyze retrieved fragments; monitor response[15,23] |
| Fixed HU cutoff on conventional CT | False uric-acid classification from overlap or partial volume | Combine attenuation distribution, size, urine pH, and clinical context[6-9] |
| Vendor or protocol shift | Loss of calibration outside development environment | External validation across scanner, energy pair, kernel, and patient size |
| Using DECT as reference for a new SECT model | Correlated error presented as chemical truth | Validate against infrared spectroscopy or x-ray diffraction[10] |
| False positive before chemolysis | Delayed definitive treatment for a nondissolvable stone | Exclude urgent indications, set response interval, track urine pH and stone burden[2-4] |
| False negative | Avoidable intervention or missed dissolution opportunity | Integrate prior stone analysis, acidic urine, clinical phenotype, and expert image review |

DECT, dual-energy computed tomography; HU, Hounsfield unit; SECT, single-energy computed tomography. An unclassified result is safer and more informative than an unsupported binary assignment.
Source: Prepared by the authors.

## 10 PRACTICAL IMAGING AND REPORTING FRAMEWORK

The radiology report should distinguish stone detection from composition characterization. It should state the number, location, maximal dimensions, obstruction, image quality, and whether each clinically relevant calculus was successfully classified. For

dual-energy studies, the report should identify the acquisition or reconstruction as dual energy, give the uric-acid versus non-uric-acid result, and disclose unclassified, mixed-color, or technically limited stones.

A useful clinical pathway begins with the question of whether composition will change care. If urgent decompression or immediate extraction is already required, dual-energy characterization may not alter the acute decision, although it can inform prevention. If a stable patient has a potentially dissolvable burden and no stone analysis, dual-energy classification can materially increase confidence before a monitored chemolysis attempt.

Conventional prediction should be framed probabilistically. A low attenuation value, acidic urine, radiolucency on plain radiography, diabetes or metabolic syndrome, and prior uric-acid analysis increase probability, but no single element is definitive. When dual energy and clinical context disagree, review of stone size, segmentation, low- and high-energy images, urine timing, prior treatment, and possible mixed composition is preferable to automatic acceptance of either result.

## 11 EVIDENCE LIMITATIONS AND FUTURE RESEARCH

The evidence base contains small uric-acid denominators, stone-level analyses that may not account for clustering within patients, variable verification, and selective exclusion of unclassified stones. Many studies report accuracy only among calculi that the software successfully mapped, which can overestimate end-to-end clinical performance. The proportion and characteristics of unclassified stones should be treated as a diagnostic outcome, not a preprocessing footnote.

Future comparative studies should enroll consecutive patients, perform a single clinically acceptable acquisition when possible, predefine pure, dominant, and any-component targets, and chemically analyze retrieved material without knowledge of imaging. Paired statistical methods should compare dual-energy and prespecified modern single-energy algorithms, with clustering by patient and stratification by size, location, body habitus, scanner, dose, and mixed composition.

Clinical-utility trials should extend beyond accuracy. They should test whether access to dual-energy classification increases appropriate chemolysis, shortens time to stone clearance, reduces procedures and radiation, avoids delayed decompression, and remains cost-effective. These outcomes would establish the value of the test within a care pathway rather than merely its ability to reproduce laboratory composition.

## 12 CONCLUSION

Dual-energy computed tomography is the best-established noninvasive imaging method for distinguishing uric-acid-dominant from non-uric-acid urinary calculi. Its principal advantage over conventional computed tomography is material discrimination based on energy-dependent attenuation rather than reliance on a single, overlapping Hounsfield-unit distribution.

Direct comparative studies favor dual energy, and meta-analytic evidence demonstrates consistently high specificity with good sensitivity. The most comprehensive synthesis estimated sensitivity of 0.88 and specificity of 0.98 for uric-acid-dominant stones, while sensitivity was lower when any uric-acid component within a mixed stone defined a positive result.

Accuracy is reduced or classification fails most often in very small stones, noisy low-dose data, large body habitus, mixed composition, and suboptimal spectral acquisition. Contemporary scanners and optimized protocols can achieve excellent performance at a dose comparable to routine stone imaging, but unclassified stones must be reported transparently.

Conventional computed tomography remains valuable and can predict uric acid with clinically useful accuracy when attenuation distribution, stone size, and urine pH are combined. Nevertheless, thresholds and machine-learning algorithms require external validation against chemical analysis before they can be considered equivalent to dual-energy classification.

Dual-energy computed tomography should be used when pre-treatment composition will change management, particularly before a monitored attempt at oral dissolution. It complements rather than eliminates clinical assessment and retrieved-stone analysis, and it must never delay urgent decompression or definitive treatment when obstruction, infection, renal risk, or uncontrolled symptoms demand intervention.

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