

Review Article

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Pharmacological Considerations in Diagnostic Radiology: Contrast Agents, Adverse Reactions, Drug–Imaging Interactions, And Patient Safety.

Guru Prakash D¹, Joel Martin J¹, Dr Naveenkumar M², Govindaraj S^{1*}

¹Assistant Professor, Department of MRIT, School of Allied Health Sciences, Vinayaka Mission's Puducherry Campus, Puducherry, India.

²Assistant Professor, Department of Pharmacology, School of Allied Health Sciences, Vinayaka Mission's Puducherry Campus, Puducherry, India.

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***Correspondence:**

Govindaraj S, Department of MRIT, School of Allied Health Sciences, Vinayaka Mission's Puducherry Campus, Puducherry, India.
Email: govindarajrit07@gmail.com

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ABSTRACT

Contrast-enhanced imaging is a pharmacological intervention as well as an imaging procedure. Iodinated contrast media (ICM), gadolinium-based contrast agents (GBCAs), and ultrasound contrast agents (UCAs) differ substantially in molecular structure, physicochemical behaviour, biodistribution, clearance, dose-response relationships, and adverse-event profiles. These differences influence how patients should be screened, how agents should be selected, and how repeated examinations should be scheduled. This structured narrative review synthesises contemporary evidence, emphasising guidance and peer-reviewed studies published predominantly from 2021 through August 2026. PubMed/MEDLINE was used for primary bibliographic verification, while Scopus and Google Scholar were used for broader discovery and citation tracking, and ResearchGate was used only as a supplementary full-text discovery source. The review focuses on pharmacokinetics and pharmacodynamics; immediate and delayed hypersensitivity; contrast-associated acute kidney injury (CA-AKI); iodine-related thyroid dysfunction; nephrogenic systemic fibrosis (NSF); gadolinium retention; UCA safety; drug–contrast issues, including metformin and laboratory-test interference; extravasation; special populations; and pharmacovigilance. Current evidence favours risk-adapted contrast administration rather than routine contrast avoidance. The clinically important determinants of risk are patient-specific: prior reaction phenotype, kidney function and active acute kidney injury, haemodynamic status, thyroid susceptibility, pregnancy or childhood, concomitant medications, exposure frequency, and the diagnostic necessity of enhancement. Major contemporary guidance also shows that some historical practices require reconsideration, particularly routine premedication and indiscriminate withholding of contrast in chronic kidney disease. The principal contribution of this review is to integrate pharmacology with radiological decision-making in a practical framework that links agent properties to individualised risk, prevention, emergency readiness, and future precision contrast administration.

Keywords: Diagnostic Radiology; Contrast Media; Iodinated Contrast Media; Gadolinium-Based Contrast Agents; Ultrasound Contrast Agents;

INTRODUCTION

Contrast media are pharmacologically distinct agents whose clinical effects and safety depend on molecular properties, dose, distribution, elimination,

patient physiology, and prior exposure. Iodinated contrast media (ICM), gadolinium-based contrast agents (GBCAs), and ultrasound contrast agents (UCAs) interact differently with X-ray photons,

magnetic relaxation, and acoustic energy.^[1–5] Contemporary safety assessment distinguishes hypersensitivity reactions from physiological or toxic effects and recognises contrast-associated acute kidney injury as multifactorial rather than necessarily causal.^[6–9] Accordingly, contrast administration requires individualised risk–benefit assessment, appropriate agent selection, exposure minimisation, and monitoring.^[2, 6, 10] This review integrates pharmacology, adverse-drug-reaction science, medication reconciliation, and workflow into a unified pharmacology-to-workflow model.

METHODOLOGY

REVIEW DESIGN AND SCOPE

This study was prepared as a structured narrative review. A narrative design was selected because the literature spans pharmacological mechanisms, guideline statements, observational cohorts, systematic reviews, meta-analyses, and practical radiology recommendations that use heterogeneous definitions and outcomes. The primary evidence window was January 2021 to August 2026, while earlier publications were retained when they remained foundational to contemporary interpretation or were incorporated by current guidelines.

INFORMATION SOURCES AND REPRODUCIBILITY

Literature discovery used PubMed/MEDLINE, Scopus, Google Scholar, and ResearchGate. PubMed was the principal source for bibliographic verification; publisher metadata was checked when needed to resolve journal, DOI, or publication-status details. Scopus and Google Scholar were used for broad discovery and citation chaining, not as sole proof of bibliographic validity. ResearchGate was treated only as a supplementary route to accessible full text. The search was updated through August 26, 2026.

Core search concepts were combined with Boolean operators and adapted to database syntax: (“contrast media” OR “contrast agent*”) AND (“iodinated” OR “gadolinium” OR “ultrasound” OR microbubble*) AND (pharmacokinetic* OR pharmacodynamic* OR hypersensitivity OR anaphylaxis OR kidney OR renal OR thyroid OR nephrogenic systemic fibrosis OR retention OR metformin OR drug interaction OR extravasation OR pregnancy OR paediatric* OR pharmacovigilance OR dose optimisation OR artificial intelligence). Additional targeted searches addressed contemporary guidance from the American College of Radiology, the American Academy of Allergy and Immunology, the European Society of Urogenital Radiology, the European Thyroid Association, and related speciality organisations.

ELIGIBILITY AND SYNTHESIS

Priority was given to human studies, systematic reviews and meta-analyses, professional guidelines and consensus statements, large cohorts, prospective studies, and clinically relevant contemporary reviews. Studies were considered on the basis of relevance to contrast pharmacology, safety, or imaging practice; bibliographic verifiability; and clinical applicability. Evidence was synthesised narratively by contrast class and safety domain. When guidelines differed, the disagreement itself was treated as a finding and interpreted in relation to evidence strength, clinical context, and the risk of both intervention and non-intervention. No quantitative meta-analysis was performed because the review question was integrative rather than effect-estimating.

PHARMACOLOGICAL BASIS OF DIAGNOSTIC CONTRAST AGENTS

ICMs are water-soluble, predominantly nonionic, low- or iso-osmolar compounds. Their principal variables include iodine concentration, osmolality,

viscosity, molecular size, hydrophilicity, injection rate, and total administered iodine. After intravascular administration, most modern ICMs distribute rapidly in the extracellular fluid space and are eliminated primarily by the kidneys without substantial metabolism. Pharmacologically, their imaging effect is therefore linked to both concentration-time behaviour and delivery parameters: iodine concentration and injection rate determine intravascular enhancement, while cardiac output, circulation time, vascular territory, and scan timing influence the resulting enhancement curve. A “minimum contrast dose” is not inherently optimal if it produces inadequate diagnostic information; the relevant goal is the lowest exposure that preserves required image quality.^[5, 11]

GBCAs contain paramagnetic gadolinium chelated to an organic ligand. The chelate is crucial because free gadolinium is biologically reactive. Clinically relevant properties include relaxivity,

thermodynamic stability, kinetic inertness, protein binding, molecular architecture, hydrophilicity, distribution, and renal elimination. Macrocyclic agents generally provide greater kinetic stability than many linear agents, which is relevant to gadolinium retention and the historical development of NSF. Contemporary safety discussions therefore require agent-level rather than class-only assessment.^[12–15]

UCAs are pharmacologically different from both ICM and GBCAs. They commonly contain gas-filled microbubbles stabilised by lipid, protein, or polymeric shells. Their short intravascular persistence, nonlinear acoustic behaviour, and largely pulmonary gas elimination produce a distinct pharmacokinetic profile. Current evidence supports a favourable safety profile, including in paediatric imaging, while severe acute reactions remain sufficiently rare that emergency preparedness should be maintained.^[16–18]

Table 1. Comparative pharmacological properties, clinical applications, and safety considerations of diagnostic contrast agents.

Characteristic	Iodinated contrast media	Gadolinium-based contrast agents	Ultrasound contrast agents
Primary modality	CT/CTA/angiography	MRI/MRA	CEUS
Imaging mechanism	X-ray attenuation	Alteration of T1/T2 relaxation	Nonlinear acoustic response
Typical distribution	Extracellular fluid	Predominantly extracellular	Intravascular microbubbles
Main elimination	Renal	Mainly renal	Gas elimination is predominantly pulmonary; shell components are handled according to agent.
Key pharmacological determinants	Iodine concentration, osmolality, viscosity, injection rate	Chelate stability, relaxivity, molecular structure, renal clearance	Gas and shell properties, route, microbubble kinetics
Important safety issues	Hypersensitivity, CA-AKI, thyroid dysfunction, extravasation	Hypersensitivity, NSF in selected historical/high-risk settings, retention	Rare hypersensitivity and cardiopulmonary events
Preferred safety approach	Individual renal/hypersensitivity assessment and dose optimisation	Agent-specific selection and renal-risk assessment	Agent-specific screening and emergency readiness

IODINATED CONTRAST MEDIA: ADVERSE REACTIONS AND PREVENTION

ACUTE REACTIONS AND HYPERSENSITIVITY

Acute reactions after ICM include transient warmth, nausea, vomiting, headache, dizziness, blood pressure changes, urticaria, angioedema, bronchospasm, hypotension, and anaphylaxis. Contemporary terminology is important because non-hypersensitivity physiological reactions are not managed in the same way as true hypersensitivity. Immediate hypersensitivity reactions occur within minutes to approximately one hour in most cases and can be mild or life-threatening; delayed reactions are typically cutaneous and may develop hours to several days later.^[1, 3, 19]

Recent evidence also demonstrates why a generic “allergy history” is an inadequate screening variable. The most clinically actionable predictor is the patient’s previous reaction to a contrast agent, including the exact agent when known, phenotype, onset, severity, treatment, and outcome. A 2026 systematic review and meta-analysis identified several associations with immediate hypersensitivity but also showed that the evidence is heterogeneous, reinforcing the need to distinguish broad population risk factors from the much stronger signal provided by a documented prior contrast reaction.^[20]

PREMEDICATION: AN AREA OF GUIDELINE CONFLICT

Premedication is one of the clearest examples of evolving practice. Earlier radiology protocols commonly emphasised corticosteroid and antihistamine premedication for patients with previous reactions. The 2025 ACR/AAAAI consensus explicitly addressed discordance between older radiology guidance and allergy practice parameters and moved the discussion toward individualised risk assessment, agent switching,

allergy evaluation in selected cases, and preparedness rather than assuming that medication prophylaxis reliably prevents severe reactions.^[2,3] The 2025 ESUR guideline similarly emphasises standardised classification, treatment readiness, agent-specific documentation, and intramuscular adrenaline as the key rescue drug for severe immediate reactions.^[19]

The practical conclusion is not that premedication should never be used. Rather, it should not be considered a substitute for risk stratification or emergency readiness. In a patient with a convincing prior severe immediate reaction, the first questions should be whether contrast is essential, whether another suitable agent can be selected, whether specialist evaluation is warranted, and whether the imaging can be performed in a setting capable of treating anaphylaxis. This is more defensible than treating all “contrast allergies” as equivalent.

CONTRAST-ASSOCIATED ACUTE KIDNEY INJURY: REFRAMING RISK

CA-AKI illustrates the difference between temporal association and causation. Post-procedure creatinine elevation remains clinically important, but the attribution of that injury directly to modern intravenous ICM is difficult because patients undergoing contrast-enhanced imaging often have multiple concurrent renal insults. Contemporary reviews emphasise renal haemodynamic changes, medullary hypoxia, oxidative stress, endothelial dysfunction, tubular cellular stress, and inflammatory signalling as plausible mechanisms, but the strength of clinical evidence linking these mechanisms to routine intravenous contrast exposure varies substantially.^[6-9]

The clinically relevant risk is concentrated in patients with active AKI, advanced CKD, dehydration, hypotension, sepsis, heart failure, haemodynamic instability, high contrast burden, repeated exposure, and concomitant nephrotoxic

drugs. These variables are also markers of severe illness, which confounds observational estimates. The modern risk message should therefore avoid both extremes: contrast is not "harmless", but the attributable renal risk of appropriately administered contemporary ICM is not equivalent to historical estimates derived from populations with less rigorous comparator methods.^[6, 8, 10]

Prevention should begin with clinical necessity rather than contrast avoidance. When enhancement is essential, the strategy is to optimise reversible risk factors, maintain appropriate hydration when clinically indicated, avoid unnecessary nephrotoxic exposure, minimise avoidable repeat examinations, and use a diagnostically adequate contrast dose. Routine use of multiple pharmacological "renal protective" agents is not supported as a universal strategy. Importantly, excessive avoidance of necessary contrast can itself reduce diagnostic accuracy and delay treatment, a problem sometimes described as "renalism".^[10]

PHARMACOKINETICS AND REPEATED CONTRAST ADMINISTRATION

Contrast pharmacokinetics directly influence repeat-imaging decisions. For iodine-based agents, renal clearance is rapid in patients with preserved kidney function, and ESUR guidance indicates that an interval of approximately 12 hours between elective examinations generally allows near-complete clearance; shorter intervals may be justified when clinical necessity requires urgent re-imaging. As renal function declines, clearance slows, and longer intervals become more appropriate.^[5] The same pharmacokinetic principle applies to GBCAs, although agent characteristics and the clinical context differ.

Repeated exposure should therefore be interpreted through cumulative clinical need, not an arbitrary universal waiting rule. In oncology, emergency medicine, vascular imaging, and interventional

practice, the diagnostic consequence of delaying imaging may exceed the theoretical benefit of prolonging an interval. Pharmacokinetic reasoning should inform rather than replace clinical judgement.

IODINATED CONTRAST AND THYROID FUNCTION

ICM provides a supraphysiological iodine load that can perturb thyroid physiology. The 2021 European Thyroid Association guideline recognises both iodine-induced hyperthyroidism and hypothyroidism, with risk concentrated in susceptible patients. Autonomous nodular thyroid disease and latent Graves disease are particularly relevant to iodine-induced hyperthyroidism, whereas autoimmune thyroid disease can predispose to hypothyroid responses.^[21]

Large contemporary observational data support the principle of targeted rather than universal screening. In a Veterans Health Administration analysis involving more than 4.2 million adults, iodine exposure was associated with a statistically significant but clinically modest absolute increase in thyroid dysfunction, supporting focused surveillance of higher-risk individuals rather than routine thyroid testing before every contrast-enhanced CT.^[22] The important pharmacological concept is susceptibility: the iodine load is predictable, whereas the endocrine response is patient-dependent.

GADOLINIUM-BASED CONTRAST AGENTS: NSF, RETENTION, AND HYPERSENSITIVITY

Modern GBCAs have a strong safety record, but their safety cannot be reduced to a single class statement because molecular architecture matters. NSF historically occurred predominantly in patients with severe renal dysfunction after exposure to less-stable group I agents. The widespread use of more

stable group II agents has substantially reduced the risk, and current practice emphasises selecting an appropriate agent rather than automatically withholding medically necessary MRI in every patient with CKD.^[12–15]

Gadolinium retention is an established analytical and imaging phenomenon. Trace amounts can remain in tissues after GBCA exposure, with greater deposition generally associated with linear agents than with macrocyclic agents. Importantly, retention and toxicity are separate propositions. Current reviews have not established a specific clinically harmful syndrome caused by gadolinium deposition in patients with normal renal function.^[12, 13] Scientific communication should therefore separate exposure, retention, biological effect, and clinical disease rather than treating them as interchangeable endpoints.

Hypersensitivity to GBCAs is less frequent than with ICM but can be severe. Prior GBCA-associated reactions should be recorded at the agent level and considered in future contrast selection. Where repeated MRI examinations are anticipated, the risk–benefit discussion should incorporate clinical necessity, prior reaction phenotype, renal function, the stability characteristics of candidate agents, and the possibility of non-contrast sequences.

ULTRASOUND CONTRAST AGENTS

UCAs occupy a distinct position in contrast pharmacology because microbubbles are intravascular acoustic tracers rather than extracellular agents. Current evidence indicates a very low incidence of severe adverse events in both adults and children. A 2026 systematic review and meta-analysis covering more than one million adult examinations and more than 36,000 paediatric patients found severe acute adverse reactions to be extremely rare, with most non-severe reactions self-limited and no meaningful safety difference between approved UCA products.^[18]

The safety advantage of CEUS should not be interpreted as the absence of risk. Agent-specific contraindications, cardiovascular considerations, pregnancy evidence limitations, and the need for immediate recognition of rare serious reactions remain relevant. The pharmacological distinction is useful because UCA risk should not be extrapolated from ICM or GBCA experience.

DRUG–CONTRAST INTERACTIONS AND LABORATORY INTERFERENCE

Medication issues during contrast administration are often misinterpreted as direct drug–contrast interactions. With metformin, the primary concern is reduced clearance during severe renal dysfunction or acute kidney injury, increasing the risk of lactic acidosis. Management should therefore consider renal function, acute illness, contrast route, and institutional guidance, rather than routine discontinuation.^[23] Other nephrotoxic drugs, including NSAIDs, aminoglycosides, and calcineurin inhibitors, may increase renal vulnerability and should be identified during medication reconciliation. Contrast agents can also interfere with selected laboratory assays. Important samples should, when feasible, be collected before contrast administration; otherwise, timing should account for contrast type and renal clearance.^[24]

CONTRAST EXTRAVASATION

Extravasation is a local administration complication rather than a systemic pharmacological toxicity, but it remains an important patient-safety issue. Risk increases with fragile veins, poor venous access, altered sensation or consciousness, injection pressure, viscosity, and power injection. The 2022 ESUR systematic review and updated guideline emphasise that clinical severity, not contrast volume alone, should determine escalation. Most cases resolve with conservative management, but severe tissue injury, neurovascular compromise, or compartment syndrome can occur.^[25]

A practical response includes stopping the injection, clinical examination, documentation, symptom management, and urgent surgical evaluation when there is evidence of significant tissue compromise. Protocols should also address staff training, communication with the patient, and standardised documentation because extravasation history may inform future venous access and injection decisions.

SPECIAL POPULATIONS

CKD is best treated as a risk modifier rather than a categorical contraindication. Assessment should consider eGFR, active AKI, haemodynamic stability, diagnostic necessity, available alternatives, and the properties of the selected contrast agent. The same principle of individualised decision-making applies to children, where weight-based dosing, renal function, vascular access, developmental considerations, and cumulative exposure require paediatric-specific protocols. Current UCA evidence is particularly reassuring in children, whereas ICM and GBCA evidence remains more adult-dominated.^[18]

Pregnancy requires modality- and agent-specific assessment. Non-contrast imaging should be used when diagnostically adequate, while contrast may be justified when the expected diagnostic benefit is clinically important and alternatives are insufficient. GBCA exposure in pregnancy should be reserved for situations in which the potential benefit outweighs the uncertain long-term foetal risk. The evidence base for some applications remains limited, so decisions should be individualised rather than governed by an absolute rule.

PHARMACOVIGILANCE AND DOCUMENTATION

Because contrast agents are administered at very high volumes globally, rare adverse reactions have population-level importance. Effective pharmacovigilance begins with accurate

documentation: exact agent, concentration, dose, route, date and time, reaction phenotype, timing, severity, treatment, outcome, and a specific recommendation for future imaging. A generic “contrast allergy” label has limited clinical utility because it does not preserve the information required for agent selection.^[1,19]

Spontaneous reporting systems can identify safety signals but are vulnerable to underreporting, stimulated reporting, missing denominators, confounding, and uncertain causal attribution. They should therefore complement, not replace, comparative observational research, registries, and structured electronic health-record data. Integrating agent-level reaction histories into imaging systems is a practical near-term priority because it can prevent unintentional re-exposure and improve consistency across institutions.

CRITICAL SYNTHESIS: WHERE GUIDELINES AND EVIDENCE CONVERGE OR DIVERGE

The reviewed evidence reveals broad agreement on several principles. First, previous contrast hypersensitivity is more actionable than nonspecific allergy history. Second, severe renal risk is concentrated in selected patients rather than uniformly distributed across all contrast recipients. Third, group II GBCAs have transformed the practical risk profile of NSF. Fourth, gadolinium retention is biologically demonstrable but should not automatically be equated with established clinical toxicity. Fifth, UCA safety is generally favourable, although emergency preparedness remains necessary.^[2,5,12,18,19]

Differences persist where evidence quality is limited or outcomes are highly context-dependent. Premedication is the clearest example: historical radiology pathways often favoured prophylaxis, whereas contemporary multidisciplinary guidance emphasises agent switching, phenotype-based assessment, and preparedness. Metformin recommendations also vary across guidelines, particularly in moderate renal impairment. These discrepancies should not be presented as simple contradictions; they reflect different tolerances for uncertainty, patient populations, local practice, and the balance between theoretical adverse-event prevention and treatment delay.^[2,3,23]

The main translational lesson is that a single “contrast safety” checklist is insufficient. A pharmacology-informed pathway asks which mechanism is relevant in the individual patient. Hypersensitivity calls for reaction characterisation and rescue preparedness; renal risk calls for kidney function and illness assessment; endocrine risk calls for targeted thyroid evaluation; gadolinium concerns call for agent selection and exposure justification; extravasation risk calls for venous access and injection assessment. This mechanism-specific approach is more precise than class-wide avoidance.

Table 2: Evidence-based clinical interpretation and management considerations for major contrast-media safety issues

Issue	Current interpretation	Practical implication
Prior contrast reaction	The most useful predictor is the documented previous reaction to a specific class/agent.	Record phenotype, severity, treatment, and culprit agent; consider alternative agent.
CA-AKI	Association after contrast is not equivalent to proven causation	Assess illness and renal risk; avoid both unnecessary contrast and unnecessary contrast denial
Premedication	Evidence and guidance are heterogeneous; not a guarantee against severe reaction	Use individualised strategy; do not substitute prophylaxis for readiness
Gadolinium retention	Deposition is established; clinically harmful effects remain unproven in normal renal function	Use contrast only when indicated, and consider agent stability for repeated use.
Iodine-related thyroid effects	Predominantly susceptibility-dependent	Target screening and follow-up to higher-risk patients
UCA adverse reactions	Severe events are extremely rare	Maintain emergency preparedness despite favourable overall safety
Metformin	Concern is indirect through renal dysfunction/AKI rather than a simple direct interaction.	Follow current renal- and institution-specific guidance.
Laboratory interference	Some assays can be affected by contrast media.	Obtain important samples before imaging when practical or account for timing

PRECISION CONTRAST ADMINISTRATION AND FUTURE DIRECTIONS

Precision contrast administration is becoming increasingly important as imaging technology and clinical data become more individualised. Patient-specific factors, including body habitus, cardiac output, renal function, vascular territory, scan

duration, clinical indication, prior reactions, and repeated exposure, may influence optimal contrast protocols. Spectral CT, photon-counting CT, advanced reconstruction, quantitative MRI, and optimised CEUS may achieve diagnostic performance with reduced contrast exposure in selected applications.

Artificial intelligence (AI) may further support this approach by identifying previous contrast reactions, predicting renal risk, optimising contrast dose and injection parameters, and tracking repeated exposure. However, predictive accuracy does not guarantee clinical utility. AI-based contrast-safety models require external validation, calibration, subgroup-bias assessment, prospective evaluation, and clinician supervision. Their immediate role should therefore remain clinical decision support rather than autonomous contrast prescribing.

The pharmacology-radiology interface is also expanding into theranostics. Microbubble systems are being investigated for ultrasound-mediated drug delivery and targeted therapy, although these applications remain largely investigational. These developments highlight the growing recognition of imaging agents as functional biomedical products whose pharmacological properties directly influence clinical use.

An important evidence gap is the inconsistent definition of outcomes such as allergy, hypersensitivity, physiological reactions, and CA-AKI, limiting comparison across studies. Future research should prioritise agent-specific exposure data, standardised reaction phenotyping, validated renal outcomes, and clinically meaningful endpoints. Large multicentre registries may provide stronger evidence for rare severe events than isolated institutional studies. Similarly, AI models should distinguish surrogate outcomes, such as laboratory-defined creatinine changes, from clinically consequential kidney injury. Greater standardisation would improve evidence comparability and reduce overinterpretation of associations.

LIMITATIONS

This review has several limitations. It is a structured narrative review and therefore does not provide pooled effect estimates or the formal risk-of-bias

framework of a systematic review. The literature is heterogeneous in patient populations, contrast products, definitions, routes of administration, and clinical endpoints. Database discovery across Scopus and Google Scholar was used to broaden retrieval, but PubMed and publisher metadata were prioritised for bibliographic verification. ResearchGate was treated only as a supplementary discovery source. In addition, guideline recommendations can vary by jurisdiction and are periodically revised; local protocols should therefore be updated against current institutional, national, and speciality guidance.

PRACTICAL PHARMACOLOGY-TO-WORKFLOW FRAMEWORK

Define the diagnostic question and determine whether contrast is necessary to achieve the required diagnostic information.

Characterise any previous contrast reaction by agent, phenotype, timing, severity, treatment, and outcome.

Assess renal function and identify active AKI, dehydration, sepsis, hypotension, or haemodynamic instability.

Review medications, with particular attention to metformin in the setting of significant renal dysfunction and to cumulative nephrotoxic burden. Screen selectively for thyroid disease, pregnancy, paediatric considerations, frailty, or other patient-specific risk modifiers.

Select the most appropriate contrast agent and protocol, using agent-specific stability and safety information where relevant.

Optimise dose, iodine concentration, injection rate, timing, and vascular access to achieve the lowest diagnostically adequate exposure.

Maintain emergency preparedness and observe for immediate reactions; provide patient-specific instructions for delayed reactions when appropriate.

Document exact agent, dose, route, reaction details, treatment, and recommendations for future imaging. Feed clinically important events into pharmacovigilance and use them to inform subsequent personalised imaging decisions.

CONCLUSION

Contrast-enhanced imaging should be understood as a coordinated pharmacological and radiological intervention. ICM, GBCAs, and UCAs possess distinct physicochemical and pharmacokinetic properties that determine their diagnostic effects and safety profiles. Contemporary evidence supports risk-adapted rather than indiscriminate avoidance of contrast. The dominant clinical variables are prior reaction phenotype, renal function and acute illness, endocrine susceptibility, medication burden, repeated exposure, agent characteristics, and diagnostic necessity.

The strongest practical change is conceptual: safety improves when the mechanism of risk is identified before a blanket precaution is applied. Modern ICM require proportionate rather than reflexive renal-risk management; GBCA selection should distinguish NSF risk from retention concerns; UCA decisions should reflect their distinct pharmacology; and hypersensitivity pathways should prioritise accurate documentation, individualised agent selection, and treatment readiness. A precision approach that links pharmacology to protocol design, electronic decision support, and pharmacovigilance has greater potential than one-size-fits-all screening. Future research should focus on prospective risk models, standardised reaction phenotyping, comparative agent studies, and clinically validated decision-support systems that improve safety without reducing diagnostic performance.

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ABBREVIATIONS

ACR, American College of Radiology; **AI**, artificial intelligence; **AKI**, acute kidney injury; **CA-AKI**, contrast-associated acute kidney injury; **CEUS**, contrast-enhanced ultrasound; **CKD**, chronic kidney disease; **CT**, computed tomography; **CTA**, computed tomography angiography; **ESUR**, European Society of Urogenital Radiology; **GBCA**, gadolinium-based contrast agent; **ICM**, iodinated contrast media; **MRA**, magnetic resonance angiography; **MRI**, magnetic resonance imaging; **NSF**, nephrogenic systemic fibrosis; **NSAIDs**, nonsteroidal anti-inflammatory drugs; **UCA**, ultrasound contrast agent.

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