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Management of Clinical Variability in Radiotherapy Delivery: Explicit Treatment-Delivery Judgment and a Three-Layer Framework

– a discussion paper

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Abstract

Radiotherapy delivery is founded on standardization, protocol adherence, and quality assurance to ensure precision, reproducibility, and patient safety. However, clinical variability remains unavoidable because patient anatomy, organ filling, immobilization conditions, physiological status, image quality, and workflow constraints can change across treatment fractions. During daily cone-beam computed tomography (CBCT)-based verification, predefined protocols and tolerance thresholds provide essential safety boundaries but do not always determine the most appropriate action in complex or borderline situations. This discussion paper examines clinical variability in radiotherapy delivery and proposes a three-layer framework for making treatment-delivery judgment explicit and governable, distinguishing a protocol-based safety baseline, a guideline-based consensus domain, and a bounded judgment-based domain. An organizational learning loop is proposed to convert recurrent judgment scenarios into explicit institutional standards through documentation, peer discussion, interdisciplinary review, standard-operating-procedure refinement, audit, and education. The paper also considers how this framework

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relates to current radiotherapy practice, where radiation therapists operate within institutional and regulatory boundaries that differ across settings. The approach supports governance, patient safety, professional education, and accountability without redefining medical decision-making authority.

Introduction

Radiotherapy is among the most technically structured fields in oncology. The treatment pathway depends on precisely defined prescriptions, treatment planning, immobilization methods, image-guidance protocols, quality-assurance procedures, and verification steps. Standardization is therefore central to minimizing errors, reducing communication failures, and maintaining reproducibility across a complex multidisciplinary workflow [1,2]. In this context, deviation from prescription dose, patient identity, treatment-site verification, equipment safety requirements, and mandatory pre-treatment checks is unacceptable.

Clinical practice nonetheless shows that not all variability can be eliminated by standardization alone. Patient anatomy and physiology can change during treatment because of tumour regression, oedema, weight change, respiratory variation, and other day-to-day factors. Immobilization devices improve reproducibility but do not eliminate inter-fraction variation. CBCT-based image-guided radiotherapy (IGRT) makes such variation visible at the treatment unit and can reveal findings that remain within tolerance but differ meaningfully from the planning condition or previous fractions [4,5,14].

This creates a practical dilemma. Radiotherapy departments require protocol adherence, yet contextual interpretation is needed during treatment delivery when protocols and action levels do not fully resolve a situation. In these moments, professional judgment is already being exercised in clinical practice. The key question is not whether judgment should exist, but how it should be recognized, bounded, documented, taught, audited, and integrated into organizational learning.

This discussion paper proposes a three-layer framework for managing clinical variability in radiotherapy delivery. It focuses on treatment-delivery judgment within an established treatment plan. It does not address medical decisions such as prescription change, dose adjustment, target delineation, treatment planning, or replanning authority. Instead, it concerns the practical, bounded decisions made during treatment delivery, such as whether a borderline CBCT finding can be managed by routine repositioning and re-imaging, whether escalation is required, or whether a recurrent judgment scenario should be converted into an explicit institutional standard.

Background and Approach

This discussion paper uses a strategic, purpose-driven selection of literature to support its statements and conceptual propositions. The approach was informed by principles of transparent narrative synthesis [3], but it was not designed as a systematic review. Relevant

sources were identified through targeted searches of PubMed and Google Scholar and through citation chaining from professional guidance documents and key papers.

Literature was selected for relevance to radiotherapy workflow standardization, IGRT and CBCT-based decision-making, adaptive radiotherapy, anatomical and preparation-related variability, radiation-therapist-led decision protocols, incident learning and risk management, clinical reasoning, organizational learning, and professional role development. Foundational work on reflective practice and organizational learning was included where conceptually relevant [18,21,22]. Because the paper is argumentative rather than systematic, no formal study-selection flow, inclusion/exclusion counts, or pooled quantitative estimates are presented. The purpose is to use a strategically selected evidence base to develop and critically discuss a practical governance framework.

Clinical Variability in Radiotherapy Delivery and the Limits of Existing Responses

Clinical variability in radiotherapy delivery arises from several interacting factors: anatomical, preparation-related, immobilization-related, imaging-related, workflow-related, and interpretation-related.

Anatomical and physiological change

Anatomical change during treatment is well recognized. Tumor regression, weight loss, oedema resolution, and organ motion can alter the relationship between the target, organs at risk, and immobilization devices. Adaptive radiotherapy has developed precisely because patient anatomy may differ between simulation and delivery and may continue to change during the treatment course [4,5]. CBCT and other image-guidance modalities allow such changes to be identified before treatment, but the presence of a visible change does not always imply immediate replanning. Many findings must be interpreted in relation to institutional action levels, preparation protocols, previous fractions, and clinical risk.

Preparation and organ-filling variability

Preparation protocols are particularly important in pelvic and abdominal radiotherapy, where bladder filling, rectal filling, bowel gas, and fasting status can alter the reproducibility of internal anatomy. A patient may remain within the department's image-guidance tolerance while showing organ filling that differs meaningfully from the planning condition. In such cases, the tolerance value provides a boundary, but the decision to proceed, repeat preparation, rebook, or escalate requires contextual judgment. Preparation-related variability also occurs in motion-management workflows; for example, incomplete or inconsistent breath-hold can alter treatment geometry and may require additional coaching, repeat acquisition, or escalation according to local criteria [32]. These responses should be understood as bounded adaptations within the institutional safety system rather than informal improvisation.

Immobilization-related variability

Immobilization devices improve reproducibility but do not eliminate variability. In prostate radiotherapy, endorectal balloons have been used to improve prostate immobilization and reduce rectal wall dose, with good reproducibility and dosimetric effects reported [6,7]. Nonetheless, daily balloon position, insertion depth, inflation shape, rectal anatomy, and patient-specific variation can differ between fractions. A balloon may be within an overall acceptable range on CBCT yet differ from previous fractions. The clinical issue is not simply whether the device is present, but whether its configuration is sufficiently reproducible for the intended treatment context.

Imaging interpretation and automation-related variability

CBCT has become a central tool for treatment verification, but image interpretation itself can carry uncertainty. Soft-tissue contrast, imaging artifacts, registration uncertainty, and inter-observer variability can affect interpretation [8,9]. Studies of CBCT-based organ delineation have reported inter-observer uncertainty, showing that image-based decisions are not mechanically determined by the imaging system alone [8]. Professional guidance on image registration and fusion supports consistent practice [9], but treatment-time interpretation of a registration result still depends on human assessment within the clinical context. Modern radiotherapy increasingly integrates automation, registration algorithms, adaptive planning platforms, and artificial intelligence. Automation reduces variability in repetitive tasks but can also expose the limits of protocol coverage; when an automated tool produces a result that is numerically acceptable yet visually concerning, human judgment remains necessary for explainability and accountability. Research on professional roles in radiation medicine likewise emphasizes that automation and artificial intelligence are more likely to reshape professional responsibility than to remove it [10].

Limits of protocol-based responses

Radiotherapy quality management has traditionally relied on protocols, checklists, quality assurance, and incident prevention. The AAPM Task Group 100 (TG-100) introduced risk-analysis methods into radiotherapy quality management, recommending that departments identify failure modes, estimate risk, and prioritize safety interventions [11]. Incident learning systems likewise capture near misses and adverse events so that departments can learn from experience rather than relying on individual memory [12,13]. Professional guidance documents also emphasize safe, structured, and auditable workflows for treatment delivery and image guidance [2,14].

These approaches are essential, but they do not eliminate the need for interpretation. Although protocols can define tolerance thresholds, escalation criteria, and imaging requirements, borderline or recurrent situations may still require judgment. A CBCT may meet numerical setup tolerances yet show recurrent patterns of organ filling, immobilization mismatch, or anatomical drift; the significance of the finding may depend on patient history, treatment site, preparation reproducibility, previous fractions, and

departmental practice. Action-level systems such as traffic light protocols are an important attempt to formalize image-guided decision-making. In lung image-guided adaptive radiotherapy, a traffic light workflow has been used to classify anatomical change and determine when treatment adaptation or review is required [15]. The Take Action Protocol described by Buijs and colleagues provides another important precedent, structuring radiation-therapist-led assessment of anatomical change on CBCT into an explicit decision tool that improved identification of clinically significant change for both radiation therapists and radiation oncologists [16]. These protocols show that treatment-delivery decisions can be made explicit, bounded, and auditable, while a residual area of contextual interpretation remains.

Professional Judgment in Treatment Delivery: Meaning and Context of Application

The meaning and scope of professional judgment

The term "professional judgment" can be misunderstood if not carefully defined. In this paper, professional judgment does not refer to independent medical decision-making. It does not include prescription modification, dose change, contouring authority beyond local credentialing, plan approval, or replanning decisions. Rather, it refers to contextual interpretation during treatment delivery within an established treatment plan, institutional policy, and escalation pathways.

The clinical-reasoning literature emphasizes that expertise involves more than simple rule application. Clinicians interpret information in context, recognize patterns, and adjust responses while maintaining accountability to standards, safety constraints, and team-based decision-making [17,18]. Models of skill acquisition also describe a progression from rule-based novice performance to context-sensitive expert judgment, in which experienced practitioners rely on accumulated situational experience and not on rules alone [19,20]. In radiotherapy, this may include recognizing that a setup condition is technically within tolerance yet discordant with previous fractions, or recognizing that recurrent borderline findings should be documented and reviewed rather than treated as isolated daily events.

This bounded form of judgment is not the opposite of standardization. When clearly defined, documented, and reviewed, it is part of a safe system. The risk arises when judgment remains tacit, inconsistent, and invisible. Invisible judgment is difficult to teach, audit, and improve. Explicit judgment, by contrast, can be integrated into education, peer review, incident learning, and standard-operating-procedure (SOP) development.

CBCT-based treatment delivery as a situation requiring judgment

CBCT-based verification is a useful reference point because it makes variability visible immediately before treatment and illustrates the difference between numerical tolerance and contextual interpretation.

Consider a generalized practice example of a prostate patient using an endorectal balloon. On one fraction, CBCT shows the balloon positioned slightly more inferiorly than at simulation. Bony and soft-tissue registration is within the department's setup tolerance, and no predefined mandatory escalation threshold is violated. However, the configuration is visibly different from previous fractions. Within institutional policy, the treatment team must decide whether the situation can be managed by routine repositioning and re-imaging or whether escalation is required. The tolerance value defines the acceptable range but does not fully determine the action.

A second generalized example concerns abdominal radiotherapy. Gradual weight loss across the treatment course does not violate a predefined imaging action threshold, yet bowel and organ filling diverge from the planning configuration. The treatment team may decide to repeat preparation, extend fasting time, rebook to a later time on the same day, or escalate if the pattern is recurrent or clinically concerning. In other words, the absence of a threshold violation does not in itself determine the most appropriate action.

These examples are not patient-level case reports. They are generalized practice examples used to illustrate the judgment space that can arise between strict protocol adherence and formal medical review. Such situations should not be left to individual habit but should be made visible within the departmental learning system.

Context of application, responsibility, and workflow variation across settings

Precedents such as the Take Action Protocol and traffic light protocols illustrate settings in which radiation therapist roles in image assessment are formally expanded [15,16]. However, professional scope, credentialing, legal responsibility, and review pathways vary across institutions and jurisdictions [14,24-26,29,30]. Accordingly, the framework does not assign universal decision authority to any single professional group. The judgment-based domain is centered on radiation therapists not because the framework assigns them additional clinical authority, but because they are typically the frontline professionals who first encounter day-to-day variation during treatment-unit image guidance. The framework therefore seeks to make this existing frontline judgment visible, bounded, and reviewable, while medical, technical, and dosimetric decisions remain with the appropriate members of the multidisciplinary team according to local policy and scope of practice.

Within locally approved boundaries, radiation therapists may acquire and register images, perform routine repositioning or repeat imaging, document the rationale for actions, and escalate findings. Medical decisions such as prescription change, treatment interruption for clinical reasons, or replanning typically require radiation oncologist involvement, while medical physicists should be involved when uncertainty is primarily technical, dosimetric, equipment-related, or linked to adaptive-system quality assurance [14,24-26]. Other professional groups may be involved according to treatment site, local credentialing, and institutional workflow.

IGRT workflows also differ among radiotherapy centers in imaging frequency, registration strategy, action levels, online versus offline review, and the degree of delegated radiation therapist decision-making. Some centers use formal radiation-therapist-led traffic-light or Take Action pathways, whereas others require earlier radiation oncologist or medical physics review [14-16,24-26]. Each institution should therefore specify in its SOP which situations can be managed at the treatment unit, which require peer review, and which trigger immediate interdisciplinary escalation. The proposed judgment-based domain is a governance template that can be mapped onto these local responsibility structures; it does not expand independent medical decision-making authority.

A Three-Layer Framework for Managing Clinical Variability

Radiotherapy delivery can be conceptualized as three interconnected domains: a protocol-based domain, a guideline-based domain, and a judgment-based domain (Table 1, Figure 1). The derivation of each component from existing literature and its relevance to CBCT-based treatment delivery is summarized in Table 2.

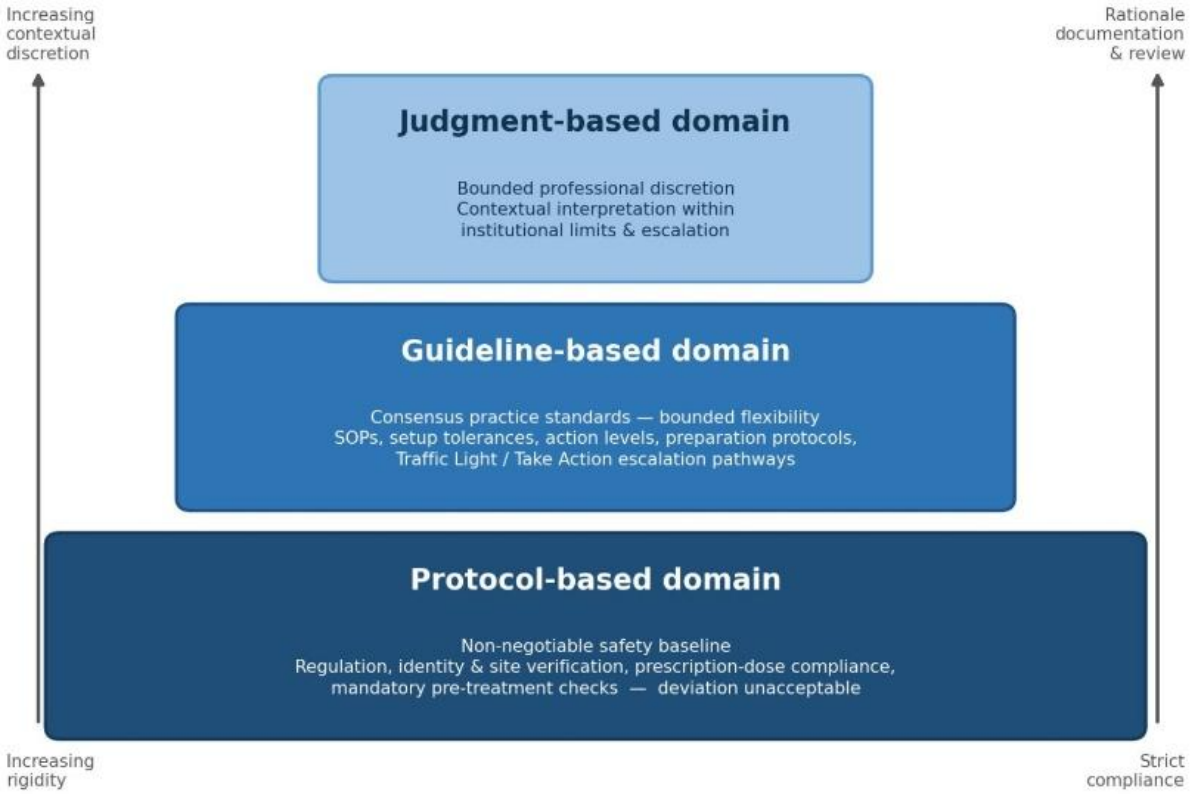


Figure 1. Three-layer framework for managing clinical variability in radiotherapy delivery. The framework distinguishes a protocol-based safety baseline, a guideline-based consensus domain, and a bounded judgment-based domain, with increasing contextual discretion toward the top and increasing rigidity and strict compliance toward the base.

Table 1. Three-layer framework for managing clinical variability in radiotherapy delivery.

Domain	Main function	Flexibility	Representative examples	Governance requirement
Protocol-based domain	Non-negotiable safety baseline	Low	Patient identity verification, prescription-dose compliance, mandatory pre-beam verification, equipment safety checks	Strict compliance, checklists, mandatory documentation
Guideline-based domain	Consensus practice standards	Moderate	CBCT registration tolerances, preparation protocols, action levels, Traffic Light / Take Action pathways	SOPs, action thresholds, escalation pathways
Judgment-based domain	Contextual interpretation within institutional limits	High but bounded	Borderline CBCT findings, recurrent organ-filling discrepancies, recurrent immobilization variation, re-imaging / escalation decisions	Rationale documentation, peer review, learning loop

Table 2. Framework derivation matrix: literature and concepts supporting each component.

Framework component	Supporting concepts / literature	Relevance to CBCT-based treatment delivery
Protocol-based domain	Quality assurance, patient identification, prescription verification, AAPM TG-100 risk analysis, safety framework	Non-negotiable beam-on safety conditions
Guideline-based domain	IGRT guidance, traffic light protocol, Take Action Protocol, standard operating procedures	Standardized action levels and escalation pathways
Judgment-based domain	Clinical reasoning, tacit knowledge, resilience engineering	Borderline situations within tolerance but meaningfully discordant with planning or prior fractions
Organizational learning loop	Incident learning, peer review, SOP refinement, education	Converts recurrent judgment scenarios into explicit standards

Protocol-based domain: non-negotiable safety baseline

The protocol-based domain includes legal regulation, patient identity verification, prescription compliance, treatment-site verification, equipment safety requirements, mandatory pre-treatment checks, and other non-negotiable conditions for beam-on. Deviation from this domain is unacceptable. This domain provides the safety floor for treatment delivery.

Guideline-based domain: consensus practice standards

The guideline-based domain includes institutional standard operating procedures, image-registration methods, site-specific setup tolerances, action levels, preparation protocols, escalation criteria, and documented review pathways. Flexibility exists but is bounded by institutional consensus and evidence-informed practice. Traffic light protocols, Take Action Protocols, and local CBCT review pathways sit primarily in this domain [15,16].

Judgment-based domain: bounded professional discretion

The judgment-based domain includes situations that are not fully specified by protocol or guideline but still require contextual interpretation during treatment delivery. This domain is bounded by institutional policy, professional scope, and escalation pathways. Examples include recurrent borderline CBCT findings, organ-filling change without threshold breach, recurrent endorectal balloon displacement, uncertainty about whether re-imaging is required, or recognition that a recurrent daily workaround should be reviewed by the team.

Practical application to CBCT-based treatment delivery

To support practical use, Table 3 maps representative CBCT-based situations to their likely domain, an immediate action, a documentation requirement, and a review trigger. These rows are generalized practice scenarios rather than patient-level records. Figure 2 presents the same logic as a decision flowchart, distinguishing non-negotiable protocol breaches, guideline or action-level breaches, and the contextual judgment zone, and showing how recurrent scenarios are routed to peer review and standard-operating-procedure (SOP) refinement.

Table 3. Practical application of the framework to CBCT-based treatment-delivery situations.

CBCT-based situation	Likely domain	Immediate action	Documentation	Review trigger
Patient identity mismatch	Protocol-based	Stop treatment	Mandatory incident record	Immediate escalation
Setup within tolerance but organ filling differs meaningfully from planning	Judgment-based	Proceed, repeat preparation, or re-image per local policy	Rationale required	If recurrent
Recurrent immobilization mismatch	Guideline / judgment overlap	Reposition and re-image	Record pattern and action	Peer / interdisciplinary review
Automated registration acceptable but visually concerning	Judgment-based	Manual review; escalate if needed	Rationale and image-review note	Repeated or high-risk cases
Repeated daily workaround	Judgment → guideline-based	Continue only within policy	Record recurrence	SOP refinement

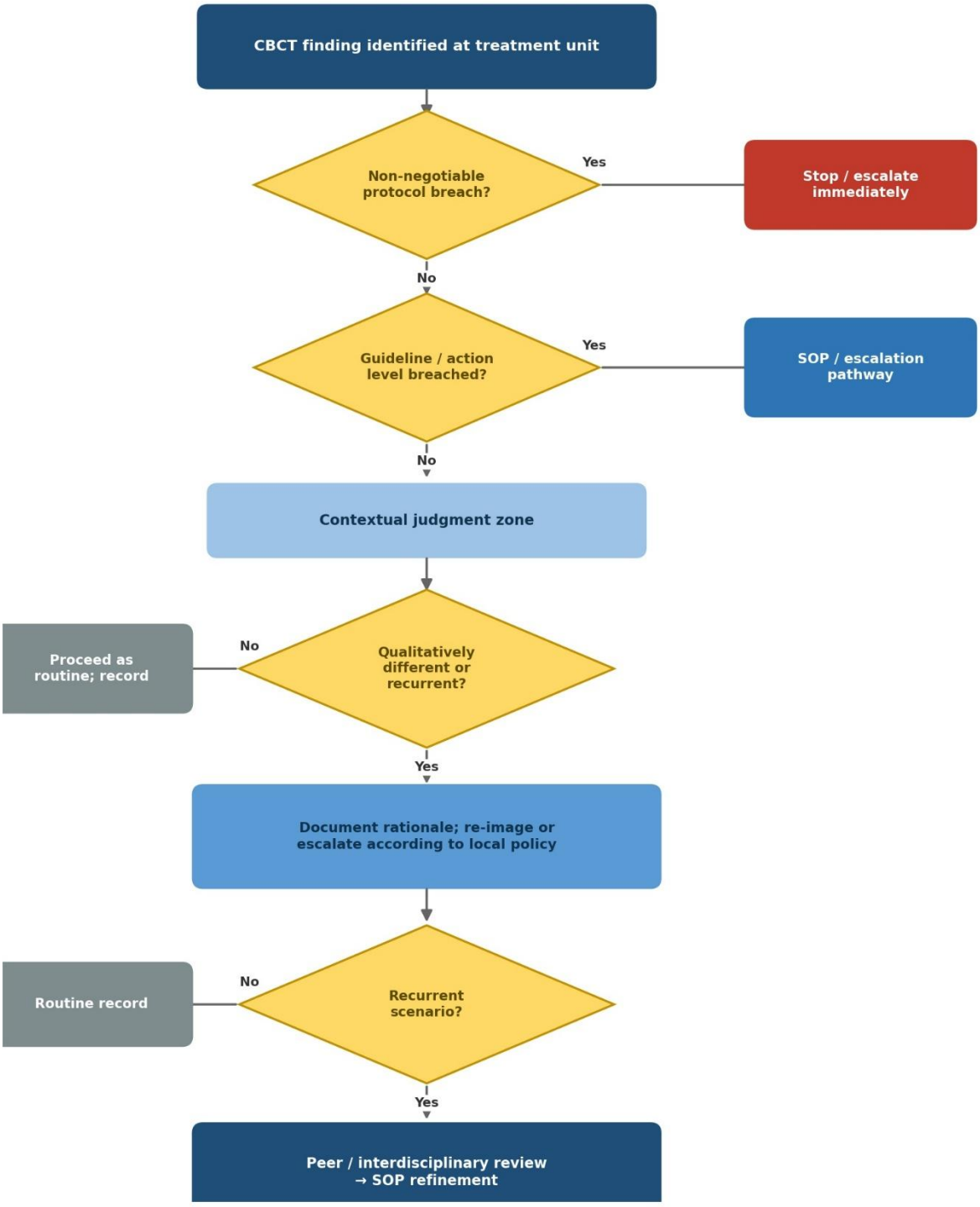


Figure 2. CBCT-based treatment-delivery decision flowchart. The flowchart distinguishes non-negotiable protocol breaches, guideline or action-level breaches, and the contextual judgment zone, and shows how findings that diverge from the planning configuration or recur across fractions are documented, re-imaged, or escalated, and how recurrent scenarios are routed to peer review and SOP refinement.

This framework is proposed as a literature-informed practical governance tool, not as an empirically validated clinical protocol. The accompanying table, checklist, and flowchart are intended as proposals to make treatment-delivery judgment visible and reviewable and should be locally adapted and validated before clinical implementation.

This layered model reframes standardization as structured rather than rigid. The protocol-based domain remains absolute. The guideline-based domain provides agreed boundaries. The judgment-based domain recognizes the residual space where contextual interpretation is necessary but must remain visible, bounded, and reviewable. Figure 1 summarizes the three domains and their relationship to flexibility and governance requirements.

Organizational-Learning-Based Governance and Educational Implications

Making tacit experience explicit

Professional judgment often begins as tacit knowledge. Experienced staff may recognize patterns that are not yet written into formal protocols. For example, they may learn that a recurrent CBCT appearance predicts setup difficulty, that certain preparation deviations often require additional time, or that a specific immobilization mismatch should trigger re-imaging before a formal action threshold is reached.

Organizational learning theory provides a way to transform such tacit knowledge into explicit institutional knowledge. Nonaka and Takeuchi described the conversion of tacit and explicit knowledge through socialization, externalization, combination, and internalization [21]. Argyris and Schön distinguished routine correction from deeper organizational learning in which underlying assumptions and procedures are revised [22]. Edmondson emphasized that healthcare organizations have frequent opportunities to learn from failure but often face barriers to speaking up, documenting, and converting experience into system improvement [23].

In this paper, an SOP is understood as a formally approved departmental procedure that specifies expected actions, role boundaries, documentation requirements, and escalation triggers for recurring clinical situations.

In radiotherapy delivery, an organizational learning loop can be structured as follows: a recurrent judgment scenario is identified during treatment delivery; the rationale for the daily action is documented in a standardized way; the scenario is discussed in peer or interdisciplinary review; the team clarifies whether it reflects an acceptable adaptation, a process weakness, or a need for escalation; institutional guidance, SOPs, action levels, or training materials are refined; the updated guidance is integrated into education, audit, and incident-learning systems; and future cases are managed with clearer shared expectations.

The Take Action Protocol is a practical example of this logic. Recurrent decisions about anatomical changes on CBCT were converted into an explicit tool that supported radiation

therapist action and radiation oncologist review [16]. Similarly, adaptive radiotherapy workflows increasingly depend on credentialing, training, and role clarity for radiation therapists and other team members [24-26]. These examples show that professional judgment can be governed without being denied. Figure 3 depicts this loop as an iterative cycle.

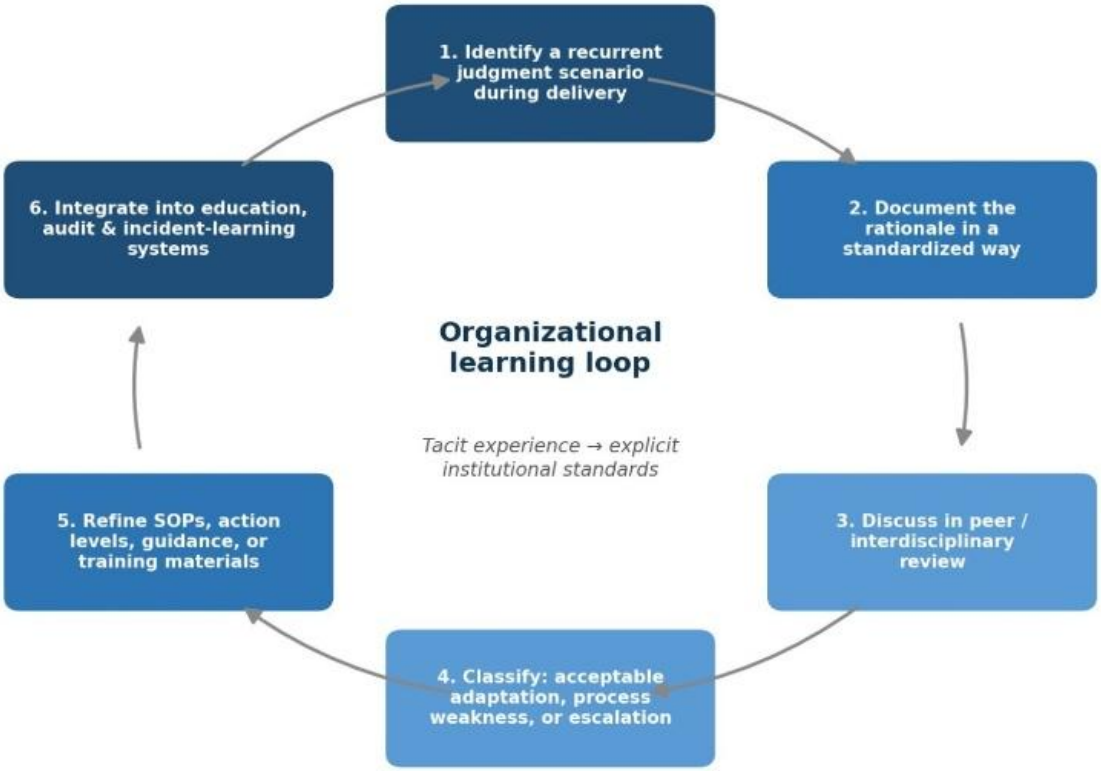


Figure 3. Organizational learning loop for making treatment-delivery judgment explicit. The loop converts a recurrent judgment scenario into explicit institutional standards through documentation, peer or interdisciplinary review, classification, refinement of standard operating procedures, and integration into education, audit, and incident-learning systems.

Relationship to incident learning and risk management

The proposed framework aligns closely with incident learning and risk-management principles. Incident learning systems capture events and near misses so that departments can identify patterns and improve safety [12,13]. TG-100 recommends proactive risk analysis and process-based quality management rather than purely prescriptive quality control [11]. More broadly, safety science has moved from models that treat human variability primarily as a source of error [27] toward resilience-based perspectives that also recognize frontline adaptive capacity as a source of safety [28]. The three-layer framework complements these approaches by identifying where variability arises and how it should be managed.

In the protocol-based domain, risk management emphasizes compliance and the prevention of unacceptable deviation. In the guideline-based domain, it focuses on maintaining consistent action levels, clear escalation criteria, and structured communication. In the judgment-based domain, it requires documentation of rationale, review of recurrent discretionary actions, and conversion of recurrent situations into explicit standards. This distinction matters: if all variability is treated as error, staff may be reluctant to report borderline situations or reflect on daily judgment; if all judgment is treated as individual autonomy, variability becomes untraceable. The layered model allows departments to distinguish unsafe deviation from acceptable adaptation and from recurrent ambiguity that should trigger organizational learning.

Implications for education and competency development

Radiation therapist education and continuing professional development should increasingly address contextual decision-making and not only procedural performance. The advanced-practice and adaptive radiotherapy literature shows that modern radiotherapy roles are evolving alongside new imaging, online adaptation, and automation tools [24-26,29,30]. These developments require structured training, credentialing, and a shared understanding of responsibility.

The three-layer framework can support education in several ways. First, it provides vocabulary that distinguishes non-negotiable protocol compliance from bounded professional discretion. Second, it can be used to design case-based learning on CBCT scenarios, organ-filling variability, immobilization mismatch, and escalation decisions. Third, it helps departments teach which situations require immediate compliance, which require SOP use, and which require documentation and team review. Finally, it helps new staff understand that expert practice is not simply "doing what feels right" but interpreting context within explicit professional and institutional boundaries.

Applicability and Limitations in the Era of Automation and Adaptive Radiotherapy

Implications for automation, artificial intelligence, and adaptive radiotherapy

As radiotherapy becomes more automated, the need to make human judgment explicit increases rather than decreases. Automation can standardize image registration, contour propagation, plan adaptation, and workflow checks, but it also creates new questions about oversight, accountability, and explainability. Artificial-intelligence-based systems can reduce routine variation while shifting professional attention toward exception handling, quality control of algorithmic output, and interpretation of borderline results [10].

Online adaptive radiotherapy illustrates this shift well. Adaptive workflows require rapid interpretation of daily anatomy, contour adaptation, plan selection or optimization, quality control, and treatment delivery within a time-constrained environment [5,24-26,31]. In such

systems, safe implementation depends on clear role boundaries, credentialing, escalation pathways, and documentation. The proposed framework may therefore be particularly relevant as departments move from traditional IGRT toward more adaptive and automated workflows.

Limitations and future directions

Several limitations should be acknowledged. First, literature was selected strategically rather than through a systematic review process, so selection may reflect the author's conceptual focus. Second, the proposed three-layer framework has not yet been empirically validated and should be locally adapted and evaluated before clinical implementation. Future work should assess its acceptability and usefulness through Delphi studies, expert consensus, multi-centre surveys, case-based classification studies, or prospective quality-improvement projects. Third, professional scope and legal responsibility differ across countries and institutions, so the judgment-based domain should be interpreted within local regulations and institutional policy. Fourth, the practice scenarios are generalized examples and do not represent patient-level evidence.

Despite these limitations, the framework may provide a useful starting point for making treatment-delivery judgment explicit. It may also help departments review recurrent ambiguity in CBCT-based workflows, strengthen documentation, and align daily practice with safety, education, and governance systems.

Conclusion

Clinical variability in radiotherapy delivery is unavoidable. Protocols and tolerance thresholds provide essential safety boundaries but do not always determine the most appropriate action in complex or borderline treatment-delivery situations. Professional judgment within institutional boundaries is therefore not an exception to safe practice but a structural component of safe system functioning.

This discussion paper has argued for a three-layer framework comprising a protocol-based safety baseline, a guideline-based consensus domain, and a bounded judgment-based domain. It also proposed an organizational learning loop to document and review recurrent judgment scenarios and convert them into explicit institutional standards. Making professional judgment visible, teachable, and auditable can strengthen patient safety, governance, education, and accountability without redefining medical decision-making authority.

Declarations

Ethics approval. This work is a discussion paper and conceptual framework; ethics approval was not required. The practice scenarios are generalized examples and contain no identifiable patient information, dates, record-level data, or patient-specific outcomes.

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Conflict of interest. The author declares no conflict of interest.

Data availability. No datasets were generated or analysed.

Use of generative AI. During the preparation of this work the author used a generative AI tool to assist with language refinement, structural organization, and formatting. After using this tool, the author reviewed and edited the content as needed, verified all cited references, and takes full responsibility for the content and accuracy of the manuscript.

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