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MINI-REVIEW

Radiation Therapists as a Human Safety Barrier in Radiotherapy: Detecting, Reporting, and Learning from Near-Miss Events

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Abstract

Background: Radiotherapy is a complex process involving many professions and many handovers of information, with error opportunities at every step. Most errors are intercepted before they reach the patient, and radiation therapists (RTTs), who carry out the final verification and delivery steps, are the professional group that most often detects them.

Objective: To review the evidence on how RTTs detect, report and learn from near-miss events, and to propose a framework for strengthening this human safety barrier.

Methods: A narrative mini-review of peer-reviewed literature, incident-learning system reports (ROSIS, SAFRON, RO-ILS), professional guidance (AAPM, ASTRO, ICRP, IAEA, WHO, UK safer-radiotherapy publications) and human-factors research.

Results: Errors arise most often in planning, simulation and documentation, but therapists are the largest single group of discoverers in multi-institutional and international databases. RTTs detect errors through independent verification, image-guided review (CBCT, kV/MV, surface guidance), observation in the treatment room and communication with the team. Detection is shaped by training, workload, situation awareness and the design of technology. Reporting is limited by fear of reprimand, hierarchy, slow systems and cognitive biases that make intercepted events seem not worth reporting. Psychological safety and just-culture principles increase reporting. Learning requires analysis at the level of the system, corrective action and feedback. Automation reduces some errors but creates new failure modes and automation bias.

Conclusions: RTTs are active safety barriers, not passive operators. We propose a Detect-Intercept-Report-Analyze-Learn-Improve-Reassess framework with RTT competencies defined for each stage, and we call for standard definitions, RTT-led investigation, safety competencies in RTT education, and AI that supports rather than replaces the vigilance of RTTs.

Keywords: Radiation Therapists; Near Miss; Incident Learning; Patient Safety; Human Factors.

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1. Introduction

Radiotherapy is a complex, multi-professional process, and its safety challenges extend beyond dose calculation and data transfer to the many human and organisational factors that affect risk [1]. An international review of radiotherapy-related events between 1976 and 2007 identified 7,741 incidents and near misses, most of which were judged preventable; among incidents without recognisable harm, 38% (n = 1,732) were related to the transfer of information [2]. The World Health Organization (WHO) Radiotherapy Risk Profile documented 3,125 patients affected by reported incidents over the same period, of whom approximately 1% (n = 38) died from radiation overdose, alongside 4,616 reported near misses [3]. Analyses of major accidental exposures by the International Commission on Radiological Protection (ICRP) have repeatedly linked catastrophic events to absent independent checks, inadequate training and poor communication [4]. ICRP Publication 112 further warned that new external-beam technologies change the nature of error, shifting risk towards software, data transfer and procedure-dependent failure modes [5].

Not every error reaches the patient. Incident-learning systems that include near misses report an average of 466 events per department per year, most of which are intercepted before treatment is affected [6]. In the Radiation Oncology Safety Information System (ROSIS), whose first five years yielded 1,074 reports from 101 centres (97.7% relating to external-beam treatment and 50% resulting in incorrect irradiation), citing studies report that 56% of incidents were found by the therapist at the treatment unit [7]. In Ezzell and colleagues' 2018 analysis of error pathways in the Radiation Oncology Incident Learning System (RO-ILS), which drew 173 events from 2,344 reports, therapists were the largest single group of discoverers (76 of 173 events), ahead of physicists (45), physicians (23) and dosimetrists (15), and five events were discovered only because the patient questioned staff [8]. Lukasz Mazur of the University of North Carolina School of Medicine, in an Agency for Healthcare Research and Quality grantee profile, stated that "approximately 40 percent of the errors reported to a national event registry were discovered by radiation therapists" [9].

RTTs carry out the final verification and delivery steps, so they occupy the last layers of what Reason described as a system's defences against error [10]. This mini-review asks how RTTs detect, report and learn from near-miss events, and how this human safety barrier can be strengthened. The discussion is organised around three pillars: DETECT, REPORT and LEARN.

2. Near-Miss Events in Radiotherapy: Definitions and Significance

Terminology in radiotherapy safety remains inconsistent, which hampers the aggregation and comparison of data beyond the local level [11]. Towards Safer Radiotherapy defined a near miss as a potential radiation incident that was detected and prevented before treatment delivery. It placed near misses within a graded classification running from reportable radiation incidents, through non-reportable and minor incidents, to near misses and other non-conformances [11]. UK guidance has since replaced "near miss" with "good catch" and "radiotherapy error" with "radiotherapy event", reflecting current patient-safety thinking [12]. Following the common formats of the Agency for Healthcare Research and Quality (AHRQ), RO-ILS distinguishes incidents, which reach the patient with or without harm, from near misses, which do not reach the patient, and from unsafe conditions, which increase the probability of an event [13]. RO-ILS further separates therapeutic radiation incidents, in which dose was not delivered as intended, from other safety incidents such as collisions or falls, and from operational or process-improvement reports [14]. The American Association of Physicists in Medicine (AAPM) consensus recommendations for incident-learning database structures

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provided the process map, taxonomy and severity scales that underpin these systems [15]. In this review, a treatment deviation is any departure from the intended plan or protocol. An adverse event is an incident that causes harm. A sentinel event is a serious, unexpected event that warrants immediate root-cause investigation.

Near misses are valuable learning opportunities because they expose the same latent weaknesses as harmful incidents, without injury to patients [16]. National AHRQ survey data cited in the RO-ILS first-year report show that higher levels of near-miss reporting are significantly correlated with fewer adverse events related to patient safety [13]. Near misses are not perceived uniformly, however. In a survey of 95 staff in an academic radiation oncology department, perceived success and willingness to report differed significantly by near-miss type, which suggests that cognitive biases shape which events are seen as worth reporting [17]. The odds of reporting near misses rose with psychological safety, and near misses perceived as evidence of resilience (“the system worked”) were processed differently from those perceived as evidence of vulnerability [18]. Ford and Evans similarly distinguished “resilient” near misses, caught by normal operations, from “vulnerable” near misses that are likely to recur, and noted that resilient near misses may never be entered into an incident-learning system [6].

Reason’s “Swiss cheese” model explains why intercepted events matter. Accidents occur when holes in successive defensive layers line up; the holes are created by active failures at the sharp end and by latent conditions in design, staffing and procedures [10]. The system approach that follows from this model asks why defences failed rather than who failed [10]. The International Atomic Energy Agency (IAEA) review of accidental exposures in radiotherapy encourages departments to use past events as a checklist for testing their own vulnerability [19]. AAPM Task Group 100 complements this retrospective learning with prospective tools (process mapping, failure mode and effects analysis [FMEA] and fault-tree analysis) that direct quality management towards the highest-risk failure modes [20]. Within this framework, the RTT is both a barrier layer and a sensor that reveals holes in the layers upstream.

3. Where RTTs Function as Safety Barriers

The radiotherapy pathway can be mapped as prescription, simulation, contouring and planning, plan and chart review, pre-treatment verification, patient set-up, image guidance, beam delivery and documentation [15]. In the University of Washington near-miss incident-learning system, events originated most often in treatment planning (33%), whereas those with the highest risk index originated during imaging and simulation [21]. Novak and colleagues mapped where errors originated and where they were detected across seven major workflow steps, including a separate detection step for therapist and on-treatment review [21]. In a ten-year Canadian series of 624 incidents, documentation errors were the most frequent (42.1%), mostly because of data-transfer errors or inadequate communication [22]. In ROSIS, many incidents that arose before treatment were not detected until later in the process, and where an incident was not caught before treatment an average of 22% of the prescribed fractions were delivered incorrectly [7].

Upstream checks are imperfect. Of 125 near misses that pretreatment physics plan review could potentially have detected, only 47 (38%) were actually detected by that review [23]. Quality-control quantification has shown that individual checks differ substantially in effectiveness and that safety depends on a layered combination of checks [24]. Within this layered system, RTT checks are distinctive because they are the last opportunity to compare the plan with the actual patient, the patient’s anatomy and the state of the machine. Table 1 summarises the error categories that RTTs can intercept.

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4. Near-Miss Detection by RTTs

4.1. Independent Verification

ASTRO's Safety is No Accident framework defines RTTs as core team members responsible for verifying patient identity, treatment parameters and set-up, and recommends standardised checklists and time-outs [25]. At Johns Hopkins, a departmental safety programme combining FMEA, risk-reduction interventions and a voluntary error and near-miss reporting system logged 253 events after it was introduced in 2007 [26]. Independent RTT verification is most effective when it is truly independent. This means the second RTT checks against source documents (prescription, plan, simulation record) rather than confirming what a colleague has already read aloud.

4.2. Image-Guided Detection

Image-guided radiotherapy (IGRT) makes the RTT an image interpreter, but it also brings its own failure modes. RO-ILS Case Study 06 describes therapists who, after noticing an image mismatch in a patient who had lost weight, re-imaged using only a lateral kV image and applied the resulting shifts, which made a geometric miss possible [27]. The lessons drawn were that RTTs must obtain image information in all three dimensions and that a second therapist should review shifts and confirm that the required images were acquired [27]. In RO-ILS Case Study 19, auto-registration for lumbar spine stereotactic body radiotherapy (SBRT) aligned to the wrong vertebral body. The alignment was approved by the therapists and a physicist, and the error was caught only when an attentive radiation oncologist reviewed it independently [28]. Across SAFRON, the University of Washington incident-learning system and the Swedish AvIC system, 21% of relevant events at the pre-treatment verification and treatment stages were judged likely to be preventable with surface-guided radiotherapy (SGRT). The most common such events were wrong isocentre (43%) and incorrect accessories (34%) [29]. Events that SGRT could potentially mitigate were generally of higher severity, yet SGRT also introduced new failure modes. The smaller proportion of accessory errors in the AvIC data may reflect mandatory SGRT use in Sweden [29]. AAPM Task Group 302 reports FMEA work in which the highest-risk SGRT failure mode was use of the wrong reference surface image, which shows that independent technologies need their own verification [30].

4.3. Treatment-Room Observation

Direct observation remains a powerful detection channel that technology does not replace. An ASTRO RO-ILS themed report on SGRT describes a laterality error in which a therapist noticed that the light field did not look right in relation to the patient's surface. The report stresses that therapists know surface anatomy exceptionally well and that any sense that a field looks wrong should be acted upon [31]. The same report notes that SGRT can catch errors related to shifts but cannot correct a wrong target contour that originates upstream [31]. Patients are also part of the observation system, since some events are discovered only because the patient questions staff [8].

4.4. Communication-Based Detection

Many interceptions depend on communication between RTTs and radiation oncologists, physicists, dosimetrists, planners and nurses rather than on the RTT acting alone. In Case Study 19, the error was intercepted because the therapists called the radiation oncologist to the machine for review, a team-based step that turned a potential incident into a near miss [28]. Missing clinical instructions, such as pacemaker clearance before radiation treatment, are a recognised near-miss category that depends on information being handed over across professions [17]. A survey of RTTs and dosimetrists in the United States and Canada found that

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the US cohort perceived better communication between radiation therapists, physicians and physicists [32].

4.5. What Makes an RTT Likely to Intercept an Error?

Detection performance can be changed. In a randomised study of 32 RTTs, simulation-based training significantly improved error detection, communication and documentation scores compared with controls ($P < .01$) [33]. Case-oriented peer review provides a further structured opportunity to detect errors, and consensus recommendations favour performing it before treatment starts [34]. AAPM Task Group 275 found that only 51% of survey respondents recorded near misses and deviations during initial plan checks, and it strongly encouraged tracking these to improve both planning and checking processes [35]. Taken together, the evidence suggests that interception is most likely when the RTT has a clear mental model of the intended treatment, a manageable workload, explicit permission to question, and checks designed around known failure modes.

Table 1. Common radiotherapy near-miss categories and examples of RTT interception

Near-miss category	Typical example	RTT interception mechanism	Key sources
Patient identity mismatch	Plan or set-up of another patient loaded; similar names	Two-identifier check, photo ID, time-out; mismatch with SGRT reference surface	[25,29]
Wrong site / laterality / vertebral level	Contralateral field; adjacent vertebra matched	Time-out against prescription and simulation record; anatomical landmark counting on CBCT; escalation to the radiation oncologist	[28,29,31]
Incorrect prescription or plan	Dose/fractionation mismatch; problematic plan approved for treatment	Independent pre-treatment chart check against signed prescription	[8,23]
Wrong machine, technique or energy	Plan scheduled on a non-matched unit; wrong energy	Record-and-verify and scheduling review at first fraction	[21,22]
Immobilisation, accessory or set-up error	Wrong mask, bolus omitted, wrong isocentre	Set-up checklist; SGRT; second-RTT verification	[29,30]
Wrong shift instructions or wrong shift performed	Incorrect couch shifts from planning	Second-RTT review of shifts; confirmation with planning/ physics	[8,27]
Incorrect image registration	Auto-registration to the wrong vertebral body	Independent visual review; landmark counting; physician approval for high-risk cases	[28]
Unexpected anatomy	Weight loss, tumour change, bladder/ bowel variation	Image review in three dimensions; referral for re-planning	[27]

 DOI: 10.67692/IODT.26.2959

Near-miss category	Typical example	RTT interception mechanism	Key sources
Incorrect treatment parameters	Field size, jaw, monitor units or shielding discrepancies	Pre-delivery parameter review; questioning unusual values	[22]
Missing or ambiguous instructions	Pacemaker clearance or bolus instruction not documented	Chart review; structured handover and communication	[17,22]
Delivery and documentation discrepancies	Fraction count, data-transfer or recording errors	End-of-day and weekly record review	[22,35]

5. Reporting Near Misses: From Detection to Disclosure

5.1. Reporting Systems

ROSIS, established in 2001, was the first international voluntary system to collect and share information on incidents and near-incidents in radiotherapy, and it set out a classification for learning from them [7]. The IAEA's Safety in Radiation Oncology (SAFRON) is an integrated, voluntary reporting and learning system that aims to improve safety by sharing safety-related events and analyses around the world and by promoting a safety culture through the analysis of near misses [36]. SAFRON explicitly encourages near-miss reporting because near misses show how effective the existing safety barriers are [37]. RO-ILS, developed by ASTRO and the AAPM with a federally listed patient safety organisation, had 46 institutions under contract by February 2015, with 33 more contracts pending [13]. Any member of staff, including radiation therapists, can enter data into RO-ILS, and information that meets the requirements receives legal protection from discovery under the Patient Safety and Quality Improvement Act [14].

Institutional systems show that reporting leads to measurable improvement. One Canadian system received an average of 11.6 reports per week and recorded reductions in actual incidents of 28% and 47% in its second and third years, which the authors attributed to interventions prompted by incident analysis [38]. Another Canadian centre reported 1,063 incident and near-miss reports between 2001 and 2007, with an average incident rate of 1.7 per 100 radiotherapy courses; actual incidents fell from 2.0 to 1.2 per 100 courses [39]. The University of Washington proposed metrics for judging the impact of a departmental near-miss incident-learning system [40]. Because increased reporting is a sign of a department that takes safety seriously, the number of reports should be read as a marker of safety culture rather than of how unsafe a department is [6].

5.2. Anonymous Versus Identified Reporting, Timing and Feedback

Anonymous systems such as SAFRON make it easier to share data across institutions [36]. Confidential systems with legal protection, such as RO-ILS, keep the reporter's context available for follow-up while limiting legal exposure [14]. Locally, identified or confidential reporting allows investigators to interview the RTT who detected the event, which is often essential for understanding how the barrier worked. Reports should be filed as close to the event as possible, ideally before the end of the shift, and every reporter should receive feedback on the analysis and the actions taken.

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5.3. Barriers to Reporting

A survey of 1,500 US radiation therapists, 528 US dosimetrists and 1,500 Canadian RTTs identified fear of reprimand, poor communication and hierarchy as the largest obstacles to error reporting [32]. In a 2022 survey of 220 radiation oncologists, RTTs and physicists in Australia and New Zealand, the weakest dimensions of safety culture were communication about error (63.9% positive) and handovers and information exchange (58.0%). Reported barriers included "it takes too long" and the burden of using several reporting systems [41]. The belief that "nothing happened" is a specific cognitive barrier for RTTs, because near misses that a therapist intercepts tend to look like evidence of success rather than of vulnerability [17,18].

5.4. Individual Behaviour Versus Organisational Culture

Reporting is a behaviour of the individual, but the organisation determines it. Marx's just-culture model separates human error, at-risk behaviour and reckless behaviour, and reserves discipline for recklessness so that honest error can be reported without blame [42]. In one academic department, culture-of-safety survey scores improved at the same time as event-learning and continuous quality-improvement programmes were introduced [43]. Table 2 summarises the barriers to and facilitators of near-miss reporting by RTTs.

Table 2. Barriers and facilitators to near-miss reporting by RTTs

Domain	Barriers	Facilitators	Key sources
Psychological / cultural	Fear of reprimand or blame; low psychological safety	Just-culture policy; leaders who visibly thank reporters; psychological safety	[18,32,42]
Hierarchical	Steep authority gradient between RTTs and physicians/physicists	Explicit authority to stop treatment and question; multidisciplinary review	[25,32]
Cognitive	"Nothing happened" belief; resilience bias towards intercepted events	Education on near-miss types; treating "good catches" as learning	[6,17,18]
System usability	Slow forms ("it takes too long"); several overlapping systems	Short, radiotherapy-specific forms; one integrated system	[41]
Feedback	No visible outcome from reports	Closed-loop feedback; publication of lessons and actions	[38,40]
Workload	Time pressure at the treatment unit	Protected reporting time; reports possible at the point of care	[33,41]
Legal / confidentiality	Fear of disclosure or litigation	Confidential, legally protected reporting (patient safety organisation)	[14]
Leadership	Weak management support for safety	Leadership-endorsed event learning and quality improvement programmes	[41,43]

6. Learning from Near Misses

Learning is a cycle: detection, reporting, investigation, analysis of root causes and system factors, corrective action, feedback and reassessment. The system approach directs analysis

 DOI: 10.67692/IODT.26.2959

towards latent conditions rather than towards the individual who was at the sharp end [10]. Standard taxonomies and causal-factor frameworks allow events to be grouped and trends to be identified across departments [15]. Prospective FMEA and fault-tree analysis, as recommended by TG-100, complement retrospective root-cause analysis by ranking failure modes before they occur [20]. Analysis of RO-ILS events into fault trees showed three common error pathways ("problematic plan approved for treatment", "wrong shift instructions given to therapists" and "wrong shift performed at treatment"), and 44% of these events resulted in incorrectly delivered treatment [8]. The UK's Towards Safer Radiotherapy recommendations, which include developing a safety culture and analysing near misses nationally, have been widely adopted and remain the basis of current guidance [11,12].

Corrective actions should be ranked by strength. Forcing functions, standardisation and redesign of processes are generally more reliable than reminders or retraining. Checklists and time-outs are core elements of safety frameworks [25]. Structured pre-treatment peer review is a recommended detection step [34]. Specific physics checklists are recommended for plan and chart review [35]. RTTs should sit on multidisciplinary review committees because they understand how frontline workarounds and barriers actually function. When RTTs see that their reports lead to changes in process, the feedback loop that keeps reporting going is closed [38].

7. Factors That Strengthen or Weaken the RTT Safety Barrier

Several factors strengthen the barrier. Clear protocols and checklists reduce the variation that hides errors [25]. All staff, including RTTs, should be explicitly empowered to stop treatment when a concern arises, and this authority should be backed by leadership [25,26]. Competency-based education that includes risk management and quality is embedded in European postgraduate benchmarking for RTTs [44]. Simulation-based training measurably improves error detection [33]. Independent verification and layered checks compensate for the limited sensitivity of any single check [23,24]. Non-punitive culture and feedback sustain reporting [42,43].

Other factors weaken the barrier. Over-reliance on automation can turn an independent check into confirmation of what the software already shows [45]. Workload and limited situation awareness erode detection performance, which is why human-factors research has focused on the cognitive demands RTTs face [33]. Ambiguous responsibility, where each professional assumes that someone else has checked, undermines the independence of layered checks [24]. Poor communication and handovers are persistent weaknesses in safety-culture surveys [41]. Hierarchy suppresses both questioning and reporting [32]. Inadequate training during the introduction of new technology has been a recurring contributor to accidental exposures [4,5]. Normalisation of deviance, in which tolerated workarounds gradually become standard practice, erodes the barrier without being noticed and is best countered by periodic audit and reassessment.

8. Emerging Challenge: Automation and Artificial Intelligence

Automation bias, the tendency to over-rely on automated advice, is a robust and generic effect across fields and includes complacency, meaning inadequate monitoring of what automated systems produce [45]. In radiotherapy, AI-based auto-contouring, synthetic CT, auto-planning and automated QA can reduce some manual errors, but they also bring new failure modes that require commissioning, case-specific QA and continued monitoring by trained staff [46]. The auto-registration near miss in lumbar SBRT shows how an automated suggestion that looks plausible can be accepted by several professionals [28]. SGRT, though protective, has itself introduced new failure modes [29]. ICRP has warned that technological transitions shift where errors occur rather than removing them [5].

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The RTT's role is therefore moving from operator to supervisor of automated systems. Supervision means understanding what the algorithm can and cannot see, knowing its typical failure signatures, and keeping the authority and confidence to override it. Mitigating automation bias requires training, accountability for verification, and interfaces that present uncertainty rather than single answers [45].

9. Proposed RTT Safety-Barrier Framework

Building on the DETECT - REPORT - LEARN pillars, we propose a seven-stage framework that sets out RTT competencies, behaviours and organisational enablers at each stage (Table 3). The framework draws on the system approach [10], prospective risk analysis [20], incident-learning practice [6] and human-factors evidence [33].

Table 3. Proposed Detect-Intercept-Report-Analyze-Learn-Improve-Reassess (DIRALIR) framework with RTT competencies

Stage	Purpose	RTT competencies and behaviours	Organisational enablers	Key sources
1. Detect	Recognise a discrepancy between intended and actual treatment	Independent verification against source documents; 3D image interpretation; surface-anatomy awareness; questioning attitude	Checklists; time-outs; SGRT/IGRT; manageable workload	[25,27,29,33]
2. Intercept	Stop the error before it reaches the patient	Stop-the-line behaviour; escalation to radiation oncologist/physicist; assertive communication	Explicit stop-treatment authority; flat hierarchy at the console	[25,26,28]
3. Report	Turn the interception into data	Timely, factual, non-judgemental reporting of near misses and unsafe conditions	Fast, radiotherapy-specific, confidential or anonymous systems; protected time	[14,36,41]
4. Analyze	Identify system causes	Participation in root-cause analysis and FMEA; describing the frontline context and workarounds	Multidisciplinary review including RTTs; standard taxonomy	[15,20,21]
5. Learn	Share lessons	Peer teaching; case-based discussion; using SAFRON/RO-ILS case studies	Departmental learning meetings; national and international shared learning	[12,27,37]
6. Improve	Implement stronger barriers	Co-design of checklists, protocols and interface changes; piloting changes	Action hierarchy favouring forcing functions and standardisation	[25,34,35]
7. Reassess	Confirm effect and detect drift	Audit of compliance; monitoring for workarounds and automation bias	Incident-learning metrics; repeat safety-culture surveys	[40,43,45]

 DOI: 10.67692/IODT.26.2959

10. Future Directions

First, standard definitions of near miss, good catch and incident are needed across national and international systems so that data can be pooled [11,12,15]. Second, reporting systems should be integrated and quick to use, since multiple overlapping systems and slow forms deter RTTs [41]. Third, RTTs should be formal members of investigation teams and should be trained in root-cause analysis and FMEA [20]. Fourth, safety competencies (human factors, just culture, incident analysis and the supervision of automation) should be built into RTT curricula and continuing professional development [44]. Fifth, research across institutions should measure the sensitivity of RTT detection, link reporting culture to outcomes, and test interventions such as simulation training [33,40]. Finally, AI should be implemented as decision support with explicit QA and human oversight, not as a replacement for RTT vigilance [46].

11. Conclusion

RTTs are active safety barriers whose ability to detect, intercept, report and learn from near misses contributes substantially to radiotherapy safety. Incident-learning data consistently place therapists among the most frequent discoverers of error [7,8]. Yet barriers to reporting and the limited sensitivity of upstream checks mean that this human barrier must be deliberately designed, resourced and protected [23,32]. Strengthening it requires just culture, explicit authority to stop treatment, training based on competencies and simulation, and thoughtful integration of automation.

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Data Availability: The data analyzed in this study were derived exclusively from previously published research articles.

Use of AI: Non generative AI was used. The authors used ChatGPT to do language edits and paraphrasing into a professional scientific style of writing.

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