

Continuity of radiotherapy services during humanitarian crises and disasters: Systematic review with implications for Indonesia

Fitrah Aulia Lisabilla*, Muthi'ah Adira Juwono

Faculty of Medicine, Universitas Brawijaya

Jalan Veteran, Kota Malang, Jawa Timur 65145, Indonesia

*Corresponding author: fitrah.lisa@gmail.com

Received: 19/07/2026

Revised: 23/08/2026

Accepted: 30/08/2026

Published Online: 12/10/2026

Abstract. Radiotherapy depends on functioning equipment, reliable electricity, specialised personnel, and repeated patient attendance, making service continuity vulnerable during disasters and humanitarian crises. This systematic review synthesised evidence on radiotherapy disruption, adaptive responses, and implications for Indonesia. A thematic systematic review with narrative synthesis was conducted following PRISMA 2020 and the approach described by Thomas and Harden. Five databases were searched in April 2026, supplemented by citation searching and grey literature. Methodological quality was assessed using MMAT, AMSTAR-2, AGREE-II, or narrative appraisal according to study type. Forty-nine sources were included: 41 (84%) concerned pandemics/PHEICs, four (8%) armed conflict, and four (8%) natural disasters. Five domains were identified: patient access, infrastructure/equipment, pandemic-specific disruption, preparedness/resilience, and workforce disruption. Treatment and scheduling changes, particularly for brachytherapy, emerged as a cross-cutting mechanism. Pandemic evidence suggested greater disruption in LMIC settings, although this could not be generalised to other crisis types. For Indonesia, single-LINAC dependency, geographic dispersion, and multi-hazard exposure indicate preparedness vulnerabilities. Four priorities are proposed: a national multi-hazard preparedness framework, equipment and power redundancy, selective hypofractionation, and formal inter-centre transfer pathways. Further research should prospectively evaluate these strategies in Indonesia and other LMIC settings.

Keywords: Radiotherapy services, Humanitarian crises, Disaster preparedness, Cancer care continuity, Indonesia

Introduction

Radiotherapy is a core component of cancer treatment, while the global cancer burden continues to increase. GLOBOCAN 2024 estimated 20.6 million new cancer cases and 9.8 million cancer deaths worldwide; Indonesia accounted for 474,083 new cases and 283,299 cancer deaths (Sung et al., 2026). Continuity depends on functioning equipment and infrastructure, reliable utilities, specialised personnel, and patients' ability to attend treatment (Man et al., 2018; Müller-Polyzou & Reuter-Oppermann, 2025). Disruption may delay or interrupt treatment, and restoration of general healthcare capacity does not necessarily restore radiotherapy services.

Crises disrupt these dependencies differently. Natural disasters may damage facilities, utilities, or transport; armed conflict may compromise safety, workforce, referral routes, and infrastructure; and pandemics may add mobility restrictions, infection-control measures, staff illness, hospital repurposing, and treatment deferral. COVID-19 generated substantially more evidence, including reductions in radiotherapy activity in England and Japan (Spencer et al.,

2021; Tamari et al., 2023). Indonesia combines geographic dispersion with limited capacity and single-machine dependence (Handoko et al., 2020), while evidence from the Philippines illustrates disruption from pandemic restrictions, hospital repurposing, and transportation barriers (de Guzman et al., 2024; Ylanan et al., 2023).

Evidence remains fragmented and concentrated on COVID-19, with fewer studies of natural disasters and armed conflict. A cross-crisis synthesis is therefore useful for identifying recurring vulnerabilities, adaptive strategies, and preparedness gaps. This review synthesised evidence on crisis-related disruption of radiotherapy continuity and translated findings cautiously into priorities for Indonesia.

Methods

This systematic review used thematic and narrative synthesis for heterogeneous evidence and followed PRISMA 2020 (Page et al., 2021), guided by Thomas and Harden (2008). Eligible sources examined radiotherapy during humanitarian crises or disasters and reported continuity-related outcomes, including interruption, delay, activity change, infrastructure/equipment or workforce disruption, access barriers, or preparedness. Editorials, conference abstracts, and sources without radiotherapy-specific continuity outcomes were excluded. English-language sources published from 2005–2025 were eligible.

PubMed, Scopus, ScienceDirect, Wiley Online Library, and the Cochrane Library were searched in April 2026. Backward citation searching and two grey-literature sources from WHO and PORI were included. A total of 1,420 records/sources were identified, deduplicated in Zotero 9.0.1, and screened in Rayyan (Ouzzani et al., 2016). Screening was independently performed by two reviewers. Data were extracted on study characteristics, crisis type, setting, disruption, access, infrastructure, workforce, adaptations, and preparedness.

Methodological appraisal used MMAT 2018 for primary studies, AMSTAR-2 for systematic/scoping reviews, AGREE-II for consensus/guideline sources, and narrative appraisal for descriptive or grey literature. Assessments were independent, and no source was excluded solely for methodological quality.

Findings were iteratively grouped into five non-mutually-exclusive domains: patient access; infrastructure/equipment; pandemic-specific disruption; preparedness/resilience; and workforce. Treatment and scheduling were retained as a cross-cutting mechanism. Quantitative findings were summarised descriptively and integrated with qualitative, consensus, and descriptive evidence.

Results and Discussion

The search identified 1,417 database records. After 288 duplicates were removed, 1,129 records were screened and 1,049 excluded. Eighty reports were retrieved, and three additional reports were identified through backward citation searching, giving 83 reports assessed at full text. Thirty-four were excluded, leaving 49 sources: 47 peer-reviewed publications and two grey-literature sources. The PRISMA flow is shown in Figure 1.

Among the 49 sources, 41 (84%) concerned pandemics/PHEICs, four (8%) armed conflict, and four (8%) natural disasters. Twenty-five sources (51%) were from HICs, 12 (24%) were from LMICs, and 12 (24%) involved multiple countries or mixed settings. Retrospective/observational designs predominated (24, 49%). Among the 37 primary studies

assessed with MMAT, the criterion for statistical adjustment for confounding was unmet in 20 studies, unclear in nine, and met in eight. Other MMAT criteria showed variable performance (Table 1). The three systematic/scoping reviews showed variable AMSTAR-2 quality (Table 2), while consensus/guideline sources showed variability across AGREE-II domains (Figure 4). No source was excluded based on appraisal results. Five non-mutually-exclusive domains were identified: patient access (39, 80%), infrastructure/equipment (26, 53%), pandemic-specific disruption (22, 45%), preparedness/resilience (21, 43%), and workforce disruption (19, 39%). Study characteristics and thematic distribution are summarised in Table 4.

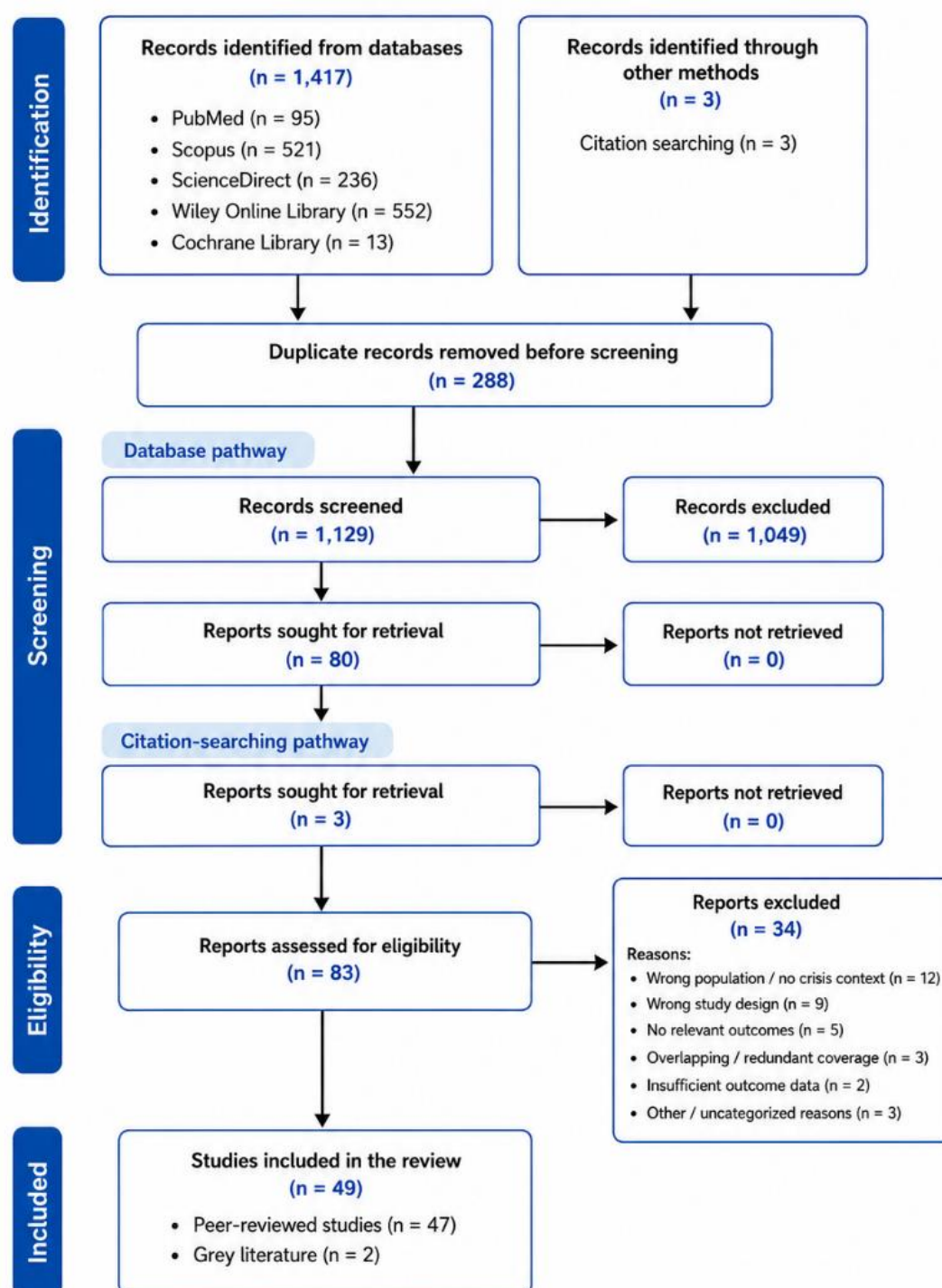


Figure 1 PRISMA 2020 Flow Diagram.

Table 1 MMAT 2018 quality assessment.

Reference (code)	S1	S2	C1	C2	C3	C4	C5
Quantitative Non-Randomised (n=27)			Representative sample	Appropriate measurement	Complete outcome data	Confounders accounted	Intervention/exposure as intended
Aynaci et al. 2022	Y	Y	Y	Y	CT	N	Y
Barik et al. 2022	Y	Y	Y	Y	CT	N	Y
Buglione et al. 2020	Y	Y	Y	Y	CT	N	Y
Chan et al. 2023	Y	Y	Y	CT	CT	N/A	Y
Cherif et al. 2021	Y	Y	CT	Y	Y	N	Y
Chiofalo et al. 2022	Y	Y	Y	Y	Y	N	Y
Corrao et al. 2020	Y	Y	N	Y	CT	N	Y
Di Muzio et al. 2022	Y	Y	Y	Y	Y	CT	Y
Fekrmandi et al. 2024	Y	Y	Y	Y	Y	N	Y
Gaudio et al. 2022	Y	Y	Y	Y	Y	Y	Y
Guerini et al. 2025	Y	Y	Y	Y	Y	N	Y
Hathout et al. 2021	Y	Y	Y	Y	CT	N	Y
Koch et al. 2020	Y	Y	Y	Y	Y	N	Y
Kolarević et al. 2022	Y	Y	Y	Y	Y	N	Y
Lee & Heo 2022	Y	Y	Y	Y	Y	N	Y
Rast et al. 2025	Y	Y	Y	Y	CT	Y	Y
Romani et al. 2021	Y	Y	Y	CT	CT	N	Y
Sabol et al. 2025	Y	Y	Y	Y	Y	Y	Y
Samper Ots et al. 2021	Y	Y	Y	Y	Y	N	Y
Sayan et al. 2022	Y	Y	Y	Y	CT	Y	Y
Spencer et al. 2021	Y	Y	Y	Y	Y	Y	Y
Tamari et al. 2023	Y	Y	Y	Y	Y	N	Y
Teckie et al. 2021	Y	Y	Y	CT	Y	N	Y
Tramacere et al. 2021	Y	Y	Y	Y	CT	N	Y
Wilson et al. 2022	Y	Y	Y	Y	Y	Y	Y
Ying et al. 2021	Y	Y	Y	Y	Y	N	Y
de Guzman et al. 2024	Y	Y	Y	Y	CT	N	Y
Quantitative Descriptive / Survey (n=8)			Sampling strategy relevant	Sample representative	Appropriate measurement	Low nonresponse bias risk	Appropriate statistical analysis
Appel et al. 2021	Y	Y	Y	CT	Y	CT	Y
Barik & Mishra 2022	Y	Y	Y	Y	Y	CT	Y
Bertholet et al. 2021	Y	Y	Y	CT	Y	CT	Y
Brazg Ferro et al. 2024	Y	Y	CT	Y	CT	N	Y
Jereczek-Fossa et al. 2020	Y	Y	Y	Y	Y	CT	Y
Kearney et al. 2020	Y	Y	Y	CT	Y	CT	Y
Oladeru et al. 2023	Y	Y	Y	Y	Y	Y	Y
Ylanan et al. 2023	Y	Y	Y	CT	Y	CT	Y
Qualitative (n=1)			Approach appropriate	Data collection adequate	Findings derived from data	Interpretation substantiated	Coherence across sources/analysis
Alkhalawi et al. 2025	Y	Y	Y	Y	CT	CT	CT

Reference (code)	S1	S2	C1	C2	C3	C4	C5
Mixed Methods (n=1)			Rationale for MM design	Components integrated	Integration outputs interpreted	Divergences addressed	Adherence to both traditions
Müller-Polyzou & Reuter-Oppermann 2025	Y	Y	Y	Y	CT	CT	CT

Y = Yes	N = No	CT = Cannot Tell
---------	--------	------------------

Note: S1/S2 (general screening questions) rated Y for all studies (published peer-reviewed research with clear research questions and analysable data; passed full-text eligibility screening). Criterion labels (C1–C5) differ by MMAT category; see category header rows above each block. Grey literature, expert consensus/guidelines, and systematic reviews are appraised separately (narrative appraisal / AGREE-II / AMSTAR-2 respectively; see Supplementary Tables S1–S3), consistent with MMAT’s intended scope for primary empirical studies only.

Table 2 AMSTAR-2 appraisal of systematic/scoping reviews (Shea et al., 2017).

AMSTAR-2 Item	Man et al. 2018 (Natural disasters & cancer care)	Basha et al. 2024 (Cancer & Syria in conflict)	Piras et al. 2022 (COVID-19 & radiotherapy)
1. PICO in research question/inclusion criteria	Y	Y	CT
2. Protocol registered before conduct ★	CT	CT	CT
3. Explains selection of study designs included	CT	Y	N
4. Comprehensive literature search strategy ★	Y	Y	N
5. Study selection performed in duplicate	CT	CT	CT
6. Data extraction performed in duplicate	Y	CT	CT
7. List of excluded studies with justification provided ★	CT	Y	N
8. Adequate description of included studies	Y	Y	CT
9. Satisfactory risk-of-bias (RoB) technique used ★	Y	Y	N
10. Funding sources of included studies reported	CT	CT	N
11. Appropriate meta-analysis statistical methods (if MA) ★	N/A	N/A	N/A
12. RoB impact assessed in meta-analysis (if MA) ★	N/A	N/A	N/A
13. RoB accounted for when interpreting results ★	CT	Y	N
14. Satisfactory explanation for heterogeneity	Y	Y	CT
15. Investigation of publication bias (if quant. synthesis)	Y	CT	N
16. Conflicts of interest of review authors reported	Y	Y	Y

Y = Yes	N = No	CT = Cannot Tell	N/A = Not applicable
---------	--------	------------------	----------------------

★ = Critical domain (AMSTAR-2). Overall confidence: Man et al. 2018 = Moderate; Basha et al. 2024 = Moderate-to-High; Piras et al. 2022 = Low.

Table 3 AGREE-II appraisal of consensus statements and guidelines (Brouwers et al., 2010).

AGREE-II Item	Alterio et al. 2020	Thomson et al. 2020	Al-Shamsi et al. 2020	PORI 2020
Scope and Purpose				
1. Overall objective(s) specifically described	6	7	6	6
2. Health question(s) specifically described	6	7	5	6
3. Target population specifically described	6	6	5	6
Scope and Purpose — domain score	83%	94%	72%	83%
Stakeholder Involvement				
4. Development group includes all relevant professional groups	3	4	6	3
5. Views/preferences of target population (patients) sought	1	1	1	2
6. Target users of the guideline clearly defined	6	6	5	5
Stakeholder Involvement — domain score	39%	44%	50%	39%
Rigour of Development				
7. Systematic methods used to search for evidence	2	5	1	2
8. Criteria for selecting evidence clearly described	2	4	1	1
9. Strengths/limitations of body of evidence described	2	4	1	1
10. Methods for formulating recommendations clearly described	6	7	2	2
11. Health benefits/side effects/risks considered	4	6	3	4
12. Explicit link between recommendations and supporting evidence	3	5	2	2
13. Guideline externally reviewed prior to publication	2	5	4	1
14. Procedure for updating the guideline provided	5	2	1	5
Rigour of Development — domain score	38%	62%	15%	21%
Clarity of Presentation				
15. Recommendations specific and unambiguous	6	7	4	6
16. Different management options clearly presented	5	6	4	5
17. Key recommendations easily identifiable	5	6	4	6
Clarity of Presentation — domain score	72%	89%	50%	78%
Applicability				
18. Facilitators/barriers to application described	2	4	2	4
19. Advice/tools for putting recommendations into practice	4	5	3	6
20. Resource implications of applying recommendations considered	2	5	2	3
21. Monitoring/auditing criteria presented	1	1	1	1
Applicability — domain score	21%	46%	17%	42%
Editorial Independence				
22. Guideline edited independently of funding body views	3	4	6	1
23. Competing interests of development group recorded/addressed	6	6	6	1
Editorial Independence — domain score	58%	67%	83%	0%

6–7 (High)	4–5 (Moderate)	1–3 (Low)
------------	----------------	-----------

Table 4 Characteristics of Included Studies

Characteristic	Category	n	%
Crisis Type	Pandemic / Public Health Emergency of International Concern (PHEIC)	41	84
	Armed conflict	4	8
	Natural disaster	4	8
Setting	High-income country (HIC)	25	51
	Low/middle-income country (LMIC)	12	24
	Multi-country / mixed settings	12	24
Study Design	Retrospective / observational	24	49
	Survey / audit	10	20
	Systematic / scoping review	3	6
	Expert consensus / policy statement	3	6
	National database / registry / interrupted time-series	3	6
	Descriptive report / reportage	3	6
	Narrative review	1	2
	Qualitative (interviews)	1	2
	Grey literature / national guideline	1	2
Thematic domain*	Patient access barriers	39	80
	Infrastructure and equipment failure	26	53
	Pandemic-specific service disruption patterns	22	45
	Preparedness and resilience strategies	21	43
	Workforce disruption	19	39

* Note: Percentages indicate the proportion of sources addressing each domain; domains were non-mutually exclusive and therefore do not sum to 100%.

How Crises Disrupt Radiotherapy

Disruption was multidimensional, with five non-mutually-exclusive domains: patient access, infrastructure/equipment, pandemic-specific disruption, preparedness/resilience, and workforce. Treatment and scheduling remained a cross-cutting mechanism.

Patient Access Barriers

Patient access was a recurrent pathway of radiotherapy disruption. Patients may be unable to reach treatment because of transportation restrictions, displacement, infection concerns, or disrupted referral pathways.

During COVID-19, transportation limitations and hospital repurposing contributed to treatment interruptions and delays (Ylanan et al., 2023; de Guzman et al., 2024). Similar barriers affected patients returning home after treatment abroad and displaced populations (Al-Shamsi et al., 2020; Sayan et al., 2022).

In Indonesia, the archipelagic geography makes transportation and inter-centre referral pathways important components of continuity planning.

Infrastructure and Equipment Failure

Infrastructure and equipment vulnerability was a major disruption pathway, particularly during natural disasters. Infrastructure damage, electricity dependence, severe weather, and wildfire were associated with reduced radiotherapy continuity or treatment adherence (Man et

al., 2018; Müller-Polyzou & Reuter-Oppermann, 2025; Fekrmandi et al., 2024; Sabol et al., 2025).

During COVID-19, disruption more often reflected hospital reorganization, infection-control measures, and service redistribution rather than physical damage (Kolarević et al., 2022; de Guzman et al., 2024). Changes in activity, scheduling, treatment interruption, and service organization were also reported across Italy, Turkey, Spain, and the United States (Alterio et al., 2020; Aynaci et al., 2022; Buglione et al., 2020; Corrao et al., 2021; Samper Ots et al., 2021; Teckie et al., 2021), with treatment interruptions also documented in India and Korea (Barik, Singh, et al., 2022; Lee & Heo, 2022; Ying et al., 2021).

In Indonesia, 60% of surveyed centres operated a single treatment machine, potentially increasing vulnerability to equipment failure (Handoko et al., 2020). However, LINAC redundancy was not directly evaluated and should therefore be considered a proposed, rather than established, resilience measure.

Pandemic-Specific Service Disruption Patterns

Pandemic/PHEIC evidence dominated the review (41/49 sources, 84%). Spencer et al. (2021) reported a 19.9% reduction in weekly radiotherapy courses in England, and Tamari et al. (2023) a 5.8% reduction in external-beam fractions in Japan. However, aggregate activity did not fully capture patient-level disruption, including treatment suspensions and delays (Guerini et al., 2025).

Indonesia also experienced reduced activity (Handoko et al., 2020), while treatment interruptions and changes in referral patterns were reported in India, Korea, and the United States (Barik, Singh, et al., 2022; Lee & Heo, 2022; Gaudio et al., 2023). Thus, disruption should be assessed using multiple indicators rather than treatment volume alone.

Services adapted through changes in fractionation, prioritisation, staffing, infection control, and models of care, alongside changes in breast radiotherapy practice and supply (Oladeru et al., 2023; Tramacere et al., 2021). However, persistent delays suggest that adaptation did not fully eliminate disruption (Rast et al., 2025).

Workforce Disruption

Workforce disruption included staff infection and quarantine, reassignment, altered working arrangements, and remote work during COVID-19 (Belkacemi et al., 2020; Jereczek-Fossa et al., 2020; Appel et al., 2021; Bertholet et al., 2021; Kearney et al., 2021). Because radiotherapy depends on multiple specialised professional groups, personnel loss or redistribution can affect the wider treatment pathway. Virtual support provided an alternative in some settings (Romani et al., 2021).

In conflict settings, workforce disruption may be more persistent. Basha et al. (2024) reported staffing shortages and healthcare-worker losses in Syria, with specialists concentrated in major centres. However, given the limited conflict evidence, this remains an interpretive pattern rather than a demonstrated crisis-specific difference.

Treatment and Scheduling Disruption

Treatment and scheduling disruption was retained as a cross-cutting mechanism, particularly in brachytherapy, where delivery depends on procedural capacity, infection control, and repeated hospital attendance. Hathout et al. (2021), Chiofalo et al. (2022), and Chan et al. (2023) reported pandemic-related brachytherapy cancellations, delays, or reduced procedural capacity, while Bhatia et al. (2022) described modified schedules in LMIC settings to reduce visits and resource requirements.

These findings show that radiotherapy may be disrupted even when treatment equipment remains operational because continuity also depends on the wider treatment pathway. However, evidence for this mechanism is predominantly pandemic-related, and its relevance to armed conflict and natural disasters remains uncertain.

How Disruption Differs by Crisis Type

Evidence was uneven: 84% concerned pandemics/PHEICs, versus 8% each for natural disasters and armed conflict. Cross-crisis differences should therefore be interpreted cautiously.

Pandemic and Public Health Emergency of International Concern (PHEIC)

Pandemic/PHEIC evidence covered the widest range of disruption mechanisms, including reduced treatment activity, access barriers, workforce disruption, scheduling changes, and service adaptation. Disruption often occurred without physical infrastructure damage through mobility restrictions, infection-control measures, staff illness, hospital repurposing, and treatment reprioritisation (Spencer et al., 2021; Tamari et al., 2023; Belkacemi et al., 2020; Jereczek-Fossa et al., 2020).

Disruption varied across settings, with resource-constrained centres particularly affected by transportation and limited capacity (Permata et al., 2020; Bhatia et al., 2022). However, the evidence does not establish LMIC status as an independent determinant of disruption, and this pattern cannot be confidently generalised to natural disasters or armed conflict.

Natural Disasters

Natural-disaster evidence focused mainly on infrastructure, utilities, transportation, and geographic access. Facility damage and electricity dependence were highlighted by Man et al. (2018) and Müller-Polyzou and Reuter-Oppermann (2025), while severe winter weather and wildfire were associated with reduced treatment adherence (Fekrmandi et al., 2024; Sabol et al., 2025). Given the small evidence base, these findings indicate plausible vulnerabilities rather than a comprehensive model of radiotherapy disruption.

Armed Conflict

Armed-conflict evidence was limited to four sources and mainly concerned patient access, displacement, workforce, and humanitarian-service challenges (Sayan et al., 2022; Basha et al., 2024; Vulpe et al., 2024; Brazg Ferro et al., 2024). Direct evidence of radiotherapy infrastructure or equipment damage was limited, unlike the natural-disaster evidence. However, given the small and heterogeneous evidence base, this difference should be interpreted cautiously.

What Systems Do to Preserve Continuity

Health systems used treatment prioritisation, fractionation modification, workforce reorganisation, infection-control measures, telehealth, and referral adaptations. However, most evidence described implemented responses rather than prospectively evaluated interventions, limiting conclusions about comparative effectiveness.

Hypofractionation

Hypofractionation was a prominent COVID-19 adaptation. Spencer et al. (2021) reported increased use of ultra-hypofractionated breast radiotherapy in England, while Piras et al. (2022) identified hypofractionation as a recurring strategy. For Indonesia, hypofractionation may reduce patient journeys during mobility restrictions, but its use should remain site- and

indication-specific, with appropriate treatment planning, image guidance, and quality assurance.

Triage and Prioritisation

Risk-adapted prioritisation was a recurrent pandemic strategy, including oncologic risk-based breast radiotherapy (Koch et al., 2020), ASTRO–ESTRO guidance for head and neck cancer (Thomson et al., 2020), and Indonesian COVID-19 guidance from PORI (2020). However, these approaches were primarily expert-guided or observational, and their effectiveness in other humanitarian crises remains unestablished.

Telehealth

Telehealth supported consultations and follow-up rather than treatment delivery (Wilson et al., 2022; Romani et al., 2021). Adaptations also included changes in treatment selection and service delivery to reduce travel, exposure, and operational burden (Aynaci et al., 2022; Oladeru et al., 2023). Telehealth therefore remains a supplementary continuity strategy, not a replacement for radiotherapy delivery.

Equipment Redundancy and Transfer Pathways

Equipment redundancy is a plausible but unvalidated strategy for single-machine centres. In contrast, referral and transfer pathways have some regional support: Ylanan et al. (2023) and de Guzman et al. (2024) highlighted transportation and referral vulnerabilities when radiotherapy access was disrupted. However, the effectiveness and feasibility of formal inter-island transfer systems in Indonesia remain unevaluated.

Structured Preparedness Frameworks

Twenty-one sources (43%) reported preparedness or resilience strategies, however, most described reactive measures rather than established preparedness frameworks (Appel et al., 2021; Barik, Behera, et al., 2022). Müller-Polyzou and Reuter-Oppermann (2025) proposed a structured continuity framework and preparedness checklist, but its effectiveness has not been prospectively evaluated.

Limitations

Evidence was highly imbalanced, with 84% of sources concerning pandemics/PHEICs and only 8% each for natural disasters and armed conflict, limiting cross-crisis comparisons. English-only inclusion may have excluded relevant evidence, while different appraisal tools were not directly comparable. Thematic classification after study review may also involve some subjectivity, despite reviewer verification.

There was overlap between some primary studies and Piras et al. (2022). Independently eligible primary studies were retained, while the review was treated as partially non-independent corroborative evidence. Heterogeneity precluded quantitative synthesis, and limited Indonesia-specific evidence—largely from COVID-19—means recommendations beyond pandemics remain evidence-informed extrapolations rather than proven interventions.

Implications for Indonesia

Indonesia has structural vulnerabilities, including a gap between radiotherapy capacity and need and substantial dependence on single-machine centres (Octavianus & Gondhowiardjo, 2022; Permata et al., 2020). The National Cancer Control Plan 2024–2034 provides a broader cancer-service framework but lacks a dedicated radiotherapy disaster-continuity framework

(Ministry of Health of the Republic of Indonesia, 2024). Broader LMIC evidence also shows disruption of essential NCD services during COVID-19, supporting integration of cancer care into wider health-system continuity planning (Alkhalawi et al., 2025).

Regional evidence from the Philippines shows how hospital repurposing, mobility restrictions, and transport barriers can disrupt referral-dependent care (de Guzman et al., 2024; Ylanan et al., 2023).

Four evidence-informed priorities emerge for Indonesia: **(1)** develop a national multi-hazard radiotherapy preparedness framework adapted to geographic and service-capacity constraints, building on existing guidance (PORI, 2020; Müller-Polyzou & Reuter-Oppermann, 2025); **(2)** consider equipment redundancy and backup-power capacity at strategically selected centres, recognizing that direct intervention evidence is lacking; **(3)** incorporate selective hypofractionation for appropriate indications to reduce treatment journeys (Spencer et al., 2021; Piras et al., 2022); and **(4)** establish and test inter-centre referral and patient-transfer pathways, informed by regional evidence on transportation and referral barriers (Ylanan et al., 2023; de Guzman et al., 2024).

These are evidence-informed proposals, not proven interventions in Indonesia. Radiotherapy continuity should therefore address patients, infrastructure, equipment, workforce, scheduling, and referral pathways as an interconnected system.

Conclusion

This review identified five domains of radiotherapy disruption: patient access, infrastructure/equipment, pandemic-specific disruption, preparedness/resilience, and workforce. Treatment and scheduling disruption, particularly in brachytherapy, emerged as a cross-cutting mechanism. Evidence was predominantly pandemic/PHEIC-related (84%), limiting comparisons with natural disasters and armed conflict.

For Indonesia, single-LINAC dependence, archipelagic geography, and exposure to multiple hazards indicate plausible vulnerabilities in service continuity, not a demonstrated national preparedness deficit. Four evidence-informed priorities are proposed: a national multi-hazard preparedness framework, selective equipment and power redundancy, appropriate hypofractionation, and formal inter-centre referral pathways. These remain preparedness proposals rather than proven interventions, warranting prospective evaluation in Indonesia and other geographically dispersed LMIC settings.

References

- Al-Shamsi, H. O., Abu-Gheida, I., Rana, S. K., Nijhawan, N., Abdulsamad, A. S., Alrawi, S., Abuhaleeqa, M., Almansoori, T. M., Alkasab, T., Aleassa, E. M., & McManus, M. C. (2020). Challenges for cancer patients returning home during SARS-COV-19 pandemic after medical tourism: A consensus report by the Emirates Oncology Task Force. *BMC Cancer*, 20(1), 641. <https://doi.org/10.1186/s12885-020-07115-6>
- Alkhalawi, E., El Berri, H., Phyto, P. P., Hag, E., Byström, M., & Hammerich, A. (2025). Maintaining essential non-communicable disease services in the Eastern Mediterranean Region during the COVID-19 pandemic. *Eastern Mediterranean Health Journal*, 31(12), 669–679. <https://doi.org/10.26719/2025.31.12.669>



- Alterio, D., Volpe, S., Marvaso, G., Turturici, I., Ferrari, A., Leonardi, M. C., Lazzari, R., Sarra Fiore, M., Bufi, G., Cattani, F., Arrobio, C., Patti, F., Casbarra, A., Cavallo, I., Mastrilli, F., Orecchia, R., & Jereczek-Fossa, B. A. (2020). Head and neck cancer radiotherapy amid COVID-19 pandemic: Report from Milan, Italy. *Head & Neck*, 42(7), 1482–1490. <https://doi.org/10.1002/hed.26319>
- Appel, S., Lawrence, Y. R., Symon, Z., & Kaidar-Person, O. (2021). COVID-RO study: The radiation oncology practice at times of COVID-19 outbreak—International survey. *Reports of Practical Oncology and Radiotherapy*, 26(1), 20–28. <https://doi.org/10.5603/RPOR.a2021.0003>
- Aynacı, Ö., Serdar, L., Rakıcı, S., Kazaz, S., Canyılmaz, E., Bahat, Z., & Zengin, A. Y. (2022). Radiotherapy in cancer treatment during the COVID-19 pandemic: One year results from northeast Turkey. *Turkish Journal of Oncology*, 37(2), 200–207. <https://doi.org/10.5505/tjo.2022.3463>
- Barik, S. K., Behera, B. K., Das Majumdar, S. K., & Parida, D. K. (2022). How prepared the radiotherapy centers are to deal with COVID-19 pandemic? A nationwide survey from 46 cancer centers across India. *Journal of Cancer Research and Therapeutics*, 18(1), 245–248. https://doi.org/10.4103/jcrt.JCRT_1525_20
- Barik, S. K., Singh, A. K., Mishra, M., Amritt, A., Sahu, D. P., Das Majumdar, S. K., & Parida, D. K. (2022). Effect of treatment interruptions and outcomes in cancer patients undergoing radiotherapy during the first wave of COVID-19 pandemic in a tertiary care institute. *Journal of the Egyptian National Cancer Institute*, 34(1), 28. <https://doi.org/10.1186/s43046-022-00129-0>
- Basha, L., Ahmed, H., Hamze, M., Ali, A. A., Alahdab, F., Marzouk, M., Sullivan, R., & Abbara, A. (2024). Cancer and Syria in conflict: A systematic review. *BMC Cancer*, 24(1), 1537. <https://doi.org/10.1186/s12885-024-13256-9>
- Belkacemi, Y., Loaganadane, G., Grellier, N., Fonteneau, G., Zaoui, G., Chauvet, B., Calais, G., Mornex, F., Giraud, P., Magné, N., Thariat, J., Troussier, I., Darai, E., Kirova, Y., Racadot, S., Hennequin, C., Rio, E., (2020). Radiation therapy department reorganization during the coronavirus disease 2019 (COVID-19) outbreak: Keys to securing staff and patients during the first weeks of the crisis and impact on radiation therapy practice from a single institution experience. *Advances in Radiation Oncology*, 5(4), 644–650. <https://doi.org/10.1016/j.adro.2020.04.039>
- Bertholet, J., Aznar, M. C., Garibaldi, C., Thwaites, D., Gershkevitch, E., Thorwarth, D., Verellen, D., Heijmen, B., Hurkmans, C., Muren, L., Røe Redalen, K., Siebert, F.-A., Schwarz, M., van Elmpt, W., Georg, D., Jornet, N., & Clark, C. H. (2021). Professional practice changes in radiotherapy physics during the COVID-19 pandemic. *Physics and Imaging in Radiation Oncology*, 19, 25–32. <https://doi.org/10.1016/j.phro.2021.06.002>
- Bhatia, R. K., Lichter, K. E., Gurram, L., MacDuffie, E., Lombe, D., Sarria, G. R., & Grover, S. (2022). Gynecologic radiation therapy in low and middle income countries during the COVID-19 pandemic. *International Journal of Gynecological Cancer*, 32(3), 446–450. <https://doi.org/10.1136/ijgc-2021-003039>
- Brazg Ferro, L., Corn, B. W., Goldzweig, G., Sultan, M., Shekel, E., & Sapir, E. (2024). Radiation therapy delivery during the 2023 Israel-Hamas war: Trust prevails over fear.

Advances in Radiation Oncology, 9, 101514.
<https://doi.org/10.1016/j.adro.2024.101514>

- Buglione, M., Spiazzi, L., Guerini, A. E., Barbera, F., Pasinetti, N., Pegurri, L., Triggiani, L., Tomasini, D., Greco, D., Costantino, G., Bragaglio, A., Bonometti, N., Liccioli, M., Mascaro, L., Alongi, F., & Magrini, S. M. (2020). Two months of radiation oncology in the heart of Italian “red zone” during COVID-19 pandemic: Paving a safe path over thin ice. *Radiation Oncology*, 15(1), 191. <https://doi.org/10.1186/s13014-020-01631-2>
- Chan, E. K., Timotin, E., Chung, P., Han, K., Milosevic, M., Schnarr, K., Sur, R., Bosche, J., & Harnett, N. (2023). A two-center experience: The impact of COVID-19 on two brachytherapy programs in Ontario—Virtual care, service suspension and radiation therapy workflow. *Journal of Medical Imaging and Radiation Sciences*, 54(3), 436–445. <https://doi.org/10.1016/j.jmir.2023.05.043>
- Cherif, M. A., Loganadane, G., Debbi, K., Coraggio, G., Ghith, S., Hadhri, A., Hassani, W., Grellier, N., To, N. H., & Belkacemi, Y. (2021). Radiation therapy delivery challenges in older patients during coronavirus disease 2019 pandemic. *Advances in Radiation Oncology*, 6(4), 100626. <https://doi.org/10.1016/j.adro.2020.11.011>
- Chiofalo, V., Di Muzio, J., Grossi, C., Olivero, F., Peruzzo, A., Madon, E., Mussano, A., & Ricardi, U. (2022). Radiotherapy management of locally advanced cervical cancer during the COVID-19 era: A single centre report on treatment approach, brachytherapy fractionation and timing. *Clinical and Experimental Obstetrics & Gynecology*, 49(11), 240. <https://doi.org/10.31083/j.ceog4911240>
- Corrao, G., Bergamaschi, L., Zaffaroni, M., Sarra Fiore, M., Bufi, G., Leonardi, M. C., Lazzari, R., Alterio, D., Cattani, F., Pravettoni, G., Mastrilli, F., Orecchia, R., Marvaso, G., & Jerezek-Fossa, B. A. (2021). COVID-19 impact in radiotherapy practice in an oncology hub: A screenshot from Lombardy, Italy. *Tumori Journal*, 107(6), 498–503. <https://doi.org/10.1177/0300891620980065>
- de Guzman, S. P. C., Chavez, L. L., & Abrilla, A. A. (2024). Single-arm cohort study on the effects of the COVID-19 pandemic on the radiation treatment of cancer patients referred to the radiation oncology division of a tertiary hospital. *Acta Medica Philippina*, 58(19), 50–55. <https://doi.org/10.47895/amp.vi0.7867>
- Di Muzio, J., Chiofalo, V., Grossi, C., Olivero, F., La Sala, S., Mussano, A., & Ricardi, U. (2022). Management of breast cancer during COVID-19 pandemic: Trends of the intervals to radiotherapy in a single center cohort. *Clinical and Experimental Obstetrics & Gynecology*, 49(11), 253. <https://doi.org/10.31083/j.ceog4911253>
- Fekrmandi, F., Gill, J., Suresh, S., Hewson, S., & Chowdhry, V. K. (2024). Impact of severe winter weather on operations of a radiation oncology department. *Advances in Radiation Oncology*, 9(6), 101491. <https://doi.org/10.1016/j.adro.2024.101491>
- Gaudio, E., Ammar, N., Gunturkun, F., Akkus, C., Brakefield, W., Wakefield, D. V., Pisu, M., Davis, R., Shaban-Nejad, A., & Schwartz, D. L. (2023). Defining radiation treatment interruption rates during the COVID-19 pandemic: Findings from an academic center in an underserved urban setting. *International Journal of Radiation Oncology, Biology, Physics*, 116(2), 379–393. <https://doi.org/10.1016/j.ijrobp.2022.09.073>



- Guerini, A. E., et al. (2025). RadiOnCOVID: Multicentric analysis of the impact of COVID-19 on patients undergoing radiation therapy in Italy. *Cancers*, 17(1), 86. <https://doi.org/10.3390/cancers17010086>.
- Handoko, Permata, T. B. M., Giselvania, A., Nuryadi, E., Octavianus, S., Jayalie, V. F., Nicholas, Khumaesa, N. E., Maharani, P., Djuita, F., Wijaya, I. G. A. G. M., Wahyono, Y., Hartanto, S., Ruhama, R., Hanum, F. J., Nawangsih P, C. H., Kuncoro, E. A. B., Fatmasari, Pasaribu, U. P., ... Gondhowiardjo, S. A. (2020). Ensuring safety and sustainability of radiotherapy services during the COVID-19 pandemic in resources constrain country: An Indonesian experience. *Radiotherapy and Oncology*, 150, 57–60. <https://doi.org/10.1016/j.radonc.2020.05.044>
- Hathout, L., Ennis, R. D., Mattes, M. D., Wagman, R. T., Grann, A., Jabbour, S. K., Singh, R., Yue, N. J., Haffty, B. G., & Vergalasova, I. (2021). The impact of COVID-19 on brachytherapy during the pandemic: A Rutgers-Robert Wood Johnson Barnabas Health multisite experience. *Advances in Radiation Oncology*, 6(1), 100600. <https://doi.org/10.1016/j.adro.2020.10.013>
- Jereczek-Fossa, B. A., Pepa, M., Marvaso, G., Bruni, A., Buglione di Monale e Bastia, M., Catalano, G., Filippi, A. R., Franco, P., Gambacorta, M. A., Genovesi, D., Iatì, G., Magli, A., Marafioti, L., Meattini, I., Merlotti, A., Mignogna, M., Musio, D., Pacelli, R., Pergolizzi, S., ... Donato, V. (2020). COVID-19 outbreak and cancer radiotherapy disruption in Italy: Survey endorsed by the Italian Association of Radiotherapy and Clinical Oncology (AIRO). *Radiotherapy and Oncology*, 149, 89–93. <https://doi.org/10.1016/j.radonc.2020.04.061>
- Kearney, M., Coffey, M., Rossi, M., & Tsang, Y., on behalf of the ESTRO ROSQC and RTTC. (2021). Future-proof radiation therapist (RTT) practice in a pandemic—Lessons learnt from COVID-19. *Technical Innovations & Patient Support in Radiation Oncology*, 17, 18–24. <https://doi.org/10.1016/j.tipsro.2021.02.001>
- Koch, C. A., Lee, G., Liu, Z. A., Liu, F.-F., Fyles, A., Han, K., Barry, A., Croke, J., Rodin, D., Helou, J., Hahn, E., Isfahanian, N., DeRocchis, J., Lofgren, S., & Purdie, T. G. (2020). Rapid adaptation of breast radiation therapy use during the coronavirus disease 2019 pandemic at a large academic cancer center in Canada. *Advances in Radiation Oncology*, 5(4), 749–756. <https://doi.org/10.1016/j.adro.2020.06.002>
- Kolarević, G., Jaroš, D., Pavičar, B., & Marošević, G. (2022). COVID-19's impact on radiotherapy in the Republic of Srpska. *Vojnosanitetski Pregled*, 79(7), 650–657. <https://doi.org/10.2298/VSP211018024K>
- Lee, S., & Heo, J. (2022). COVID-19 pandemic: A new cause of unplanned interruption of radiotherapy in breast cancer patients. *Medical Oncology*, 39(1), 5. <https://doi.org/10.1007/s12032-021-01604-9>
- Man, R. X. G., Lack, D. A., Wyatt, C. E., & Murray, V. (2018). The effect of natural disasters on cancer care: A systematic review. *The Lancet Oncology*, 19(9), e482–e499. [https://doi.org/10.1016/S1470-2045\(18\)30412-1](https://doi.org/10.1016/S1470-2045(18)30412-1)
- Ministry of Health of the Republic of Indonesia. (2024). *National cancer control plan 2024–2034: Indonesia's strategy for fighting cancer*.

- Müller-Polyzou, R., & Reuter-Oppermann, M. (2025). Radiotherapy continuity for cancer treatment: Lessons learned from natural disasters. *PLOS ONE*, 20(9), e0308056. <https://doi.org/10.1371/journal.pone.0308056>
- Octavianus, S., & Gondhowiardjo, S. (2022). Radiation therapy in Indonesia: Estimating demand as part of a national cancer control strategy. *Applied Radiation Oncology*, 11(1), 35–42.
- Oladeru, O. T., Dunn, S. A., Li, J., Coles, C. E., Yamauchi, C., Chang, J. S., Cheng, S. H.-C., Kaidar-Person, O., Meattini, I., Ramiah, D., Kirby, A., Hijal, T., Marta, G. N., Poortmans, P., Bellon, J. R., ... Ho, A. Y. (2023). Looking back: International practice patterns in breast radiation oncology from a case-based survey across 54 countries during the first surge of the COVID-19 pandemic. *JCO Global Oncology*, 9, e2300010. <https://doi.org/10.1200/GO.23.00010>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>
- Perhimpunan Onkologi Radiasi Indonesia. (2020). *Pedoman pelayanan onkologi radiasi pada pandemi COVID-19* [Clinical guideline for radiation oncology services during the COVID-19 pandemic].
- Piras, A., Venuti, V., D'Aviero, A., Cusumano, D., Pergolizzi, S., Daidone, A., & Boldrini, L. (2022). COVID-19 and radiotherapy: A systematic review after 2 years of pandemic. *Clinical and Translational Imaging*, 10(6), 611–630. <https://doi.org/10.1007/s40336-022-00513-9>
- Rast, M., Tehrani-Banihashemi, A., Fadavi, P., Nojomi, M., Hatami, D., Ansari, K., & Ahmadi, S. A. Y. (2025). Delays in chemotherapy and radiotherapy of breast cancer during COVID-19 pandemic. *Journal of Infection and Public Health*, 18(3), 102657. <https://doi.org/10.1016/j.jiph.2025.102657>
- Romani, C., Conlon, M., Oliver, M., Leszczynski, K., Hunter, M., Lam, K., Spadafora, S., & Pearce, A. (2021). The operation of Canada's only virtually operated radiation oncology service during the COVID-19 pandemic. *Advances in Radiation Oncology*, 6(3), 100634. <https://doi.org/10.1016/j.adro.2020.100634>
- Sabol, R. A., Walsh, C. J., Densley, S., Medhat, Y., Baniel, C. C., Krishna, A., Baiyee, C. T., Meltzer, D., Boscardin, J., Witztum, A., Pitts, N., Paulsson, A. K., Luh, J. Y., Zalavari, L., Yom, S. S., & Lichter, K. (2025). Wildfire disruptions and cancer care: A multi-institutional study of radiotherapy treatment adherence in Northern California. *Journal of Climate Change and Health*, 26, 100530. <https://doi.org/10.1016/j.joclim.2025.100530>
- Samper Ots, P. M., et al. (2021). Impact of COVID-19 on patients in radiotherapy oncology departments in Spain. *Radiotherapy and Oncology*, 161, 148–151. <https://doi.org/10.1016/j.radonc.2021.06.001>
- Sayan, M., Eren, M. F., Kilic, S. S., Kotek, A., Oskeroğlu Kaplan, S., Duran, O., Cukurcayır, F., Babalıoğlu, I., Derinalp Or, O., Ozturk, G. A., Eroglu, C., Teke, F., Kurtul, N.,



- Kutuk, T., Ceylaner Bicakci, B., Senyurek, S., Aktan, M., Mamidanna, S., Ohri, N., ... Atalar, B. (2022). Utilization of radiation therapy and predictors of noncompliance among Syrian refugees in Turkey. *BMC Cancer*, 22(1), 532. <https://doi.org/10.1186/s12885-022-09558-5>
- Spencer, K., Jones, C. M., Girdler, R., Roe, C., Sharpe, M., Lawton, S., Miller, L., Lewis, P., Evans, M., Sebag-Montefiore, D., Roques, T., Smittenaar, R., & Morris, E. (2021). The impact of the COVID-19 pandemic on radiotherapy services in England, UK: A population-based study. *The Lancet Oncology*, 22(3), 309–320. [https://doi.org/10.1016/S1470-2045\(20\)30743-9](https://doi.org/10.1016/S1470-2045(20)30743-9)
- Sung, H., Filho, A. M., Laversanne, M., Ferlay, J., Siegel, R. L., Soerjomataram, I., Jemal, A., & Bray, F. (2026). Global cancer statistics 2024: GLOBOCAN estimates of incidence and mortality worldwide for 34 cancers in 186 countries. *CA: A Cancer Journal for Clinicians*, 76(4), e70090. <https://doi.org/10.3322/caac.70090>
- Tamari, K., Kishigami, M., Nagata, Y., Mizowaki, T., Kodaira, T., Onishi, H., Ogawa, K., Shioyama, Y., Shigematsu, N., & Uno, T. (2023). The impact of the COVID-19 pandemic on radiotherapy delivery in Japan: An observational study based on the national database. *Cancer Medicine*, 12(22), 21032–21040. <https://doi.org/10.1002/cam4.6661>
- Teckie, S., Andrews, J. Z., Chen, W. C.-Y., Goenka, A., Koffler, D., Adair, N., & Potters, L. (2021). Impact of the COVID-19 pandemic surge on radiation treatment: Report from a multicenter New York area institution. *JCO Oncology Practice*, 17(9), e1270–e1277. <https://doi.org/10.1200/OP.20.00619>
- Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Medical Research Methodology*, 8(1), 45. <https://doi.org/10.1186/1471-2288-8-45>
- Thomson, D. J., Palma, D., Guckenberger, M., Balermipas, P., Beitler, J. J., Blanchard, P., Brizel, D., Budach, W., Caudell, J., Corry, J., Corvo, R., Evans, M., Garden, A. S., Giralt, J., Grégoire, V., Harari, P. M., Harrington, K., Hitchcock, Y. J., Johansen, J., ... Yom, S. S. (2020). Practice recommendations for risk-adapted head and neck cancer radiotherapy during the COVID-19 pandemic: An ASTRO-ESTRO consensus statement. *Radiotherapy and Oncology*, 151, 314–321. <https://doi.org/10.1016/j.radonc.2020.04.019>
- Tramacere, F., Niccoli Asabella, A., Portaluri, M., Altini, C., Ferrari, C., Bardoscia, L., & Sardaro, A. (2021). Impact of the COVID-19 pandemic on radiotherapy supply. *Radiology Research and Practice*, 2021, 5550536. <https://doi.org/10.1155/2021/5550536>
- Vulpe, H., et al. (2024). Design and implementation of a humanitarian cancer care programme for Ukrainian refugees in Moldova and Romania. *The Lancet Oncology*, 25(3), 289–291. [https://doi.org/10.1016/S1470-2045\(23\)00629-0](https://doi.org/10.1016/S1470-2045(23)00629-0)
- Wilson, C., Romaniuk, H., Orellana, L., White, V., Foroudi, F., & Livingston, P. M. (2022). Failure to attend radiation oncology appointments during COVID-19: Analysis of data from an Australian public hospital. *Journal of Medical Imaging and Radiation Oncology*, 66(6), 874–880. <https://doi.org/10.1111/1754-9485.13425>
- World Health Organization. (2020). *COVID-19 and NCDs: Snapshot across 163 countries*.

- Ying, X., Bi, J., Ding, Y., Wei, X., Wei, W., Xin, F., Xiao, C., Hu, D., Verma, V., & Han, G. (2021). Management and outcomes of patients with radiotherapy interruption during the COVID-19 pandemic. *Frontiers in Oncology*, 11, 754838. <https://doi.org/10.3389/fonc.2021.754838>
- Ylanan, A. M. D., Cañal, J. P. A., Pineda, J. C., & Valmonte, D. J. S. (2023). Radiation therapy amidst the COVID-19 pandemic in the Philippines: When guidelines are not enough. *Acta Medica Philippina*, 57(1), 34–40. <https://doi.org/10.47895/amp.vi0.3790>