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Original Article

Radiotherapy at the limits of age: evolving fractionation strategies, symptom palliation, and survival in nonagenarians

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ABSTRACT

Background and purpose: Advances in radiotherapy (RT) techniques have facilitated the increasing use of hypofractionated treatment schedules, which may be particularly advantageous for elderly patients by reducing treatment burden while maintaining acceptable toxicity. This study aimed to evaluate survival and symptom palliation and to investigate whether different fractionation approaches affected toxicity and clinical outcomes in nonagenarian patients.

Materials and methods: This single-center retrospective cohort included 199 nonagenarians treated with RT between 2005 and 2023. Fractionation was classified as normofractionated (NF-RT), hypofractionated (HF-RT: >2Gy) and ultra-hypofractionated (UHF-RT: ≥5Gy). Outcomes were symptom control, acute ≥ Grade 2 (G2) toxicity, and overall survival (OS).

Results: Median age at RT was 92 years (range 90–101); 42% received curative and 58% palliative RT. Median OS of all patients was 11 months (palliative treatment: 7 months), with 1- and 5-year OS rates of 47% and 11% respectively. Overall, symptom improvement was documented in 73% of patients, with particularly high frequencies of improvement in tumor-related bleeding (95%) and ulceration (80%), pain improved in 65%. Acute ≥ G2 toxicity occurred in 21% (G3, 5%). Generally, UHF-RT and HF-RT had lower odds of ≥ G2 toxicity than NF-RT, however they were treated with lower doses (EQD2) to smaller target volumes. After adjustment for confounding factors, the hazards for all-cause death were only slightly higher for HF-RT and UHF-RT compared to NF-RT. Oligometastatic patients had almost identical survival as those without metastases, patients with breast cancer had a better survival than those with other entities.

Conclusion: RT in selected nonagenarians achieved high frequencies of palliation with low severe toxicity. Hypofractionation was well tolerated without clear impact on survival.

Introduction

As age is one of the leading risk factors for cancer, the number of nonagenarian patients with cancer is expected to substantially increase in the coming years, paralleling increasing life expectancy in industrialized countries [1]. In Upper Austria, a region of approximately 1.5 million inhabitants, the population aged 90 years and older almost doubled from about 7400 in 2005 to 13,500 in 2023 [2].

Data on nonagenarian oncologic patients remains limited, as most studies define “elderly” as individuals aged above 65 or 75 years, with nonagenarians representing only a small minority [3,4]. Patients aged 90 years and above present unique challenges for oncologic treatment, as treatment strategies must often be individually adapted to account for advanced chronologic age, reduced functional organ capacity, and comorbidities. With limited data, there is no blue print of how to modify treatment. In particular, chemotherapy carries an increased risk of

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adverse events, if doses are not adapted [3,5]. Radiotherapy (RT) as a non-invasive treatment modality with few systemic side effects represents an attractive option for nonagenarian oncologic patients in palliative and curative settings [6–8]. Retrospective data from unselected oncologic nonagenarians suggest that RT is generally well tolerated, with relatively few high-grade side effects [4,5]. Median overall survival is limited and ranges from 5.4 to 24 months [5,6]. Thus, especially in patients treated with palliative intent, short courses with higher doses per fraction seem to be advisable. However, the impact of altered fractionation on treatment-related toxicity and survival in nonagenarians remain poorly characterized. Similarly, while symptom palliation is a major therapeutic goal in this population, systematic data on its effectiveness are lacking.

In the present study, we aim to address these gaps by characterizing nonagenarian oncology patients undergoing RT, evaluate the extent of achieved symptom relief, and analyze the impact of different fractionation schemes on both toxicity and survival.

Materials and methods

Patients

This single-center retrospective study included all 199 nonagenarian patients treated at the department of Radiation Oncology of the Ordensklinikum Linz, Austria between January 2005 and July 2023. Previously published data from Kocik et al. [4] was incorporated, with follow-up extended by six years. Ethical approval was obtained from the Ethics Committee of the Medical Faculty at Johannes Kepler University Linz (No.: 1220/2023).

Parameters

Treatment intent was classified as either curative or palliative based on documented tumor board recommendations, taking into account the extent of tumor spread. The patients performance status was measured using the ECOG (Eastern Cooperative Oncology Group) scale [7]. The age-adjusted Charlson Comorbidity Index (ACCI) was used to classify prognostic comorbidities [8,9]. Patient records and hospital files were reviewed for tumor entity, RT treatment strategy, primary symptoms, and symptom burden during and after completion of RT. Acute toxicities were retrospectively graded according to the Common Terminology Criteria for Adverse Events (CTCAE) V5 [10]. RT treatment regimens were categorized by fractionation as normofractionated (NF-RT), hypofractionated (HF-RT) with doses per fraction above 2 Gy, or ultra-hypofractionated RT (UHF-RT) with single doses of 5 Gy or more. Vital status was ascertained via civil registries up to 27 March 2025; for 13/199 (6.5%) no death was registered, and they were considered alive at cut-off and censored.

Statistical analyses

Descriptive statistics report absolute and relative frequencies for categorical variables, median and interquartile range (IQR) for continuous variables, just as minimum and maximum, if informative, stratified by treatment intent. Time-to-death since start of RT is analyzed using Kaplan-Meier survival curves, stratified by treatment intent and tumor entity. Main symptoms and symptom control are reported descriptively.

Logistic regression models are used to quantify the effect of fractionation strategy on toxicity $>$ G1 and Cox proportional-hazards regression models to quantify the effect of fractionation on overall survival (OS). All models were subsequently adjusted for potential confounders, including tumor spread (diffuse vs. localized or oligo-metastasized), treatment intent, treatment modality (3D-conformal radiotherapy vs. Intensity-Modulated Radiotherapy/ Volumetric Modulated Arc Therapy (IMRT/VMAT)), and entity-specific treatment strategies regarding fractionation. To derive the effect of fractionation on OS we additionally adjusted for age, sex, low ECOG score (0 and 1), and ACCI. For the regression-type models we derived odds ratio (OR) and hazard ratio (HR) estimates, respectively, along with 95% confidence intervals (CI). Missing data were handled using multiple imputation by chained equations. The imputation model included all variables used in the regression analyses, just as the following: age at start of radiotherapy, sex, toxicity (CTCAE v5), vital status, follow-up time, cohort, dose per fraction, total delivered dose, number of fractions, treatment modality, symptoms, oligometastatic status, Instrumental Activities of Daily Living (IADL), ACCI, diffuse metastases, and polypharmacy. A total of m = 100 imputed datasets were generated to ensure stable estimates given the proportion of missing data. Estimates from regression analyses were combined across imputed datasets using Rubin's rules.

Analyses were performed using the Statistical Analysis Software Package (SPSS, IBM SPSS Statistics for Windows, Version 26.0, IBM Corp., Armonk, NY, USA), and R with additional R packages [11–15].

Results

The study included 199 nonagenarian patients (88 males, 111 females), aged 90 to 101 years, with a median age of 92 years. Curative RT was received by 84 patients (42%), and palliative RT by 115 (58%). Most patients (n = 124, 62%) had no known distant metastases, while 41 (21%) had diffuse metastatic disease, and 15 (8%) had oligo-metastatic disease; 18 patients were treated for hematologic malignancies.

Among the 107 patients with available ECOG status (documented only after 2017), one-third had a score of 0–1, whereas scores $>$ 1 were more frequent in those receiving palliative treatment (75% vs. 54%). ACCI scores ranged from 0 to 9 with a median of 4 (IQR: 2–6). One-third of patients had an ACCI score of 2, reflecting a low comorbidity load. Fifty percent of palliative patients had an ACCI $>$ 4, compared with 24% in the curative-intent group. The most common comorbidities included renal disease, diabetes, peripheral vascular disease, and dementia.

The most frequent tumor entity was cutaneous malignancy (n = 45, 23%), predominantly squamous cell carcinoma (n = 32), mainly localized at the scalp. Of these, two-thirds received definitive RT and one-third adjuvant/additive treatment. Earlier treatments employed NF regimens (58–70 Gy), whereas later approaches included more frequently HF and UHF schedules (e.g., 5 × 9 Gy).

The second most common tumor entity was gynecological malignancies (n = 28, 14%), including cervical (n = 8), endometrial (n = 7), vaginal (n = 7), and vulvar tumors (n = 6), generally treated with conventional fractionation (50–60 Gy). In highly palliative situations, a short regimen of 10 × 3 Gy was used in order to control bleeding (n = 8).

Among the 23 patients with primary breast cancer, 13 underwent curative treatment, including 10 who received adjuvant therapy. In the adjuvant setting, fractionation was 25 x 2 Gy in 3 patients, 15x2.67 Gy in 6 and 5x5.2 Gy in 1 patient. In patients with metastatic disease (n = 10), palliative RT for painful bone metastases was the most common indication (n = 6).

Among 18 patients with prostate cancer, four received definitive RT for the primary tumor (Gleason score 8 or 9), while the most common indication for RT was bone metastases (n = 10). Patients with lymphoma (n = 14, predominantly diffuse large B-cell lymphomas) were treated with doses of 36–40 Gy using normofractionated or moderately hypofractionated regimens.

For more detailed tabulation of treatment indications and regimens as well as the rare instances of surgery and systemic therapy administered in temporal proximity to RT see Supplementary Tables S1-S5 and the subsequent section. Information regarding the institutional decision-making process can be found in the Supplementary Material as well.

Median OS for the entire patient group was 11 months (95% CI: 9–13), with a 1-year and 5-year OS of 47% and 11%, respectively. OS differed by metastatic state: 14 months (95% CI: 11 – 17) for non-metastasized patients, 15 months (95% CI: 4 – 26) for those with

oligometastases, 3 months (95% CI: 1 – 5) for diffusely metastasized. Median OS was substantially longer in the curative (19 months, 95% CI: 15 – 23) than in the palliative-treatment group (7 months, 95% CI: 5 – 9). The respective 1- and 5-year OS probabilities were 68% and 17% for curative, vs. 31% and 7% for palliative treatment (Fig. 1A).

Patients treated for breast cancer had improved median OS of 25 months (95% CI: 13–38) compared to 10 months (95% CI: 7–13) for the rest of the cohort (Fig. 1B). In univariate analysis, breast cancer was associated with lower mortality (HR 0.55; 95% CI 0.35–0.87). These patients had slightly higher median scores for both the ACCI (4.5 vs. 4.0) and ECOG status (ECOG: 2.5 vs. 2.0), and received curative treatment more frequently (57% vs. 41%).

Tumor-related symptoms were documented in 136 patients. The most frequently reported primary symptoms were pain (n = 60, 44%), followed by tumor-associated bleeding (n = 21, 15%) and ulceration (n = 19, 14%). Information on symptom change was available for 111 patients. Among these, clinical improvement during or after the completion of RT was observed in 81 cases (73%). Symptom relief was most notable in patients treated for tumor bleeding and ulceration, with improvement documented in 95% and 80% of cases. Pain relief was achieved in 65% of patients (31 out of 48) (Table 2).

Toxicity data were available for 175 patients. Overall, RT was well tolerated as most patients (n = 138, 79%) experienced no or only mild symptoms (grade G0 or G1). Grade 2 toxicities occurred in 26 patients (15%), grade 3 toxicities in 8 (5%). Grade 3 toxicities were most commonly mucositis or dermatitis after head, neck or pelvic irradiation. Three (2%) grade 5 toxicities were reported (2 pneumonitis, 1 radiogenic brain swelling) (See Table 1; the distribution of toxicity grades by category is provided in Supplementary Table S6). 8 patients with local re-irradiations had no acute ≥ G3 toxicities.

Twenty-two patients discontinued therapy prematurely before the planned cumulative dose was reached; the median survival in this group was 1 month. The most common reasons for discontinuation were patient choice and comorbidity-related death (see Supplementary Table S7 for details).

Regarding fractionation 43% received NF-, 38% HF-, and 20% UHF-RT. By trend, the median target volumes and EQD2 were smaller with stronger hypofractionation although the distributions are wide and overlapping (see Supplementary Table S9 and Fig. S5). UHF-RT had the lowest crude odds of high toxicity, with 0.2-fold odds of UHF-RT compared to NF-RT (OR = 0.20, 95% CI: 0.04–0.90). HF-RT also showed reduced odds for ≥ G2 toxicity compared to NF-RT (OR = 0.53, 95% CI: 0.24–1.18). Considering all HF-RT regimens in the dataset, the effect resembled HF-RT versus NF-RT (OR = 0.41, 95% CI: 0.20–0.87), as there were twice as many HF-RT than UHF-RT. These associations remain largely the same if adjusted for confounding (Fig. 2A).

In crude survival analyses, both UHF-RT and HF-RT had higher hazards of all-cause death compared to NF-RT. However, after adjusting for confounding, these effects largely attenuated, with HR estimates for HF-RT and UHF-RT compared to NF-RT being consistent with either slight protective or harmful effects (HF-RT: HR 1.15, 95% CI 0.80–1.65; UHF-RT: HR 1.23, 95% CI 0.77–1.95) (Fig. 2B).

Discussion

In this cohort of 199 nonagenarians receiving radiotherapy, the most frequent malignancies were skin, gynecological, breast, and prostate cancers, as well as lymphomas. Median overall survival from start of RT was 11 months and 1-year and 5-year rates were 47% and 11%, respectively, consistent with prior studies [5,6], and slightly higher than the 9-months median OS previously reported for the first 93 patients of this cohort treated between 2005 and 2015 [4]. Survival differed markedly by metastatic burden: patients with no or few (≤5) metastases had a median survival roughly five times longer than those with disseminated metastatic spread, supporting the consideration of more intensive treatment approaches in non-metastasized nonagenarians, especially in those with good performance status. For example, 9 breast cancer patients underwent tumor resection with adjuvant RT, achieving a median OS of 39 months and 3 received definitive RT for non-metastatic prostate cancer. In both patient groups, RT was in most cases combined with endocrine therapy.

By contrast, survival was extremely limited in patients with disseminated metastases, with 38% dying within a month and 90% within three months after RT. With such a short life expectancy, condensed treatment regimens or even no active anti-tumor therapy might be the best choice. In this population the major treatment goal is symptom palliation or prevention of imminent symptoms. If active treatment is chosen it should be well tolerated and highly active in symptom palliation. In our cohort, symptom improvement was substantial, ranging from 65% for pain relief to 95% for tumor bleeding. These data support the effectiveness of RT, preferentially short courses, in nonagenarians with tumor-associated symptoms. The proportion of 65% pain relief for bone metastases is in line with data in younger patients [16,17] and palliation of tumor bleeding was even higher than in a

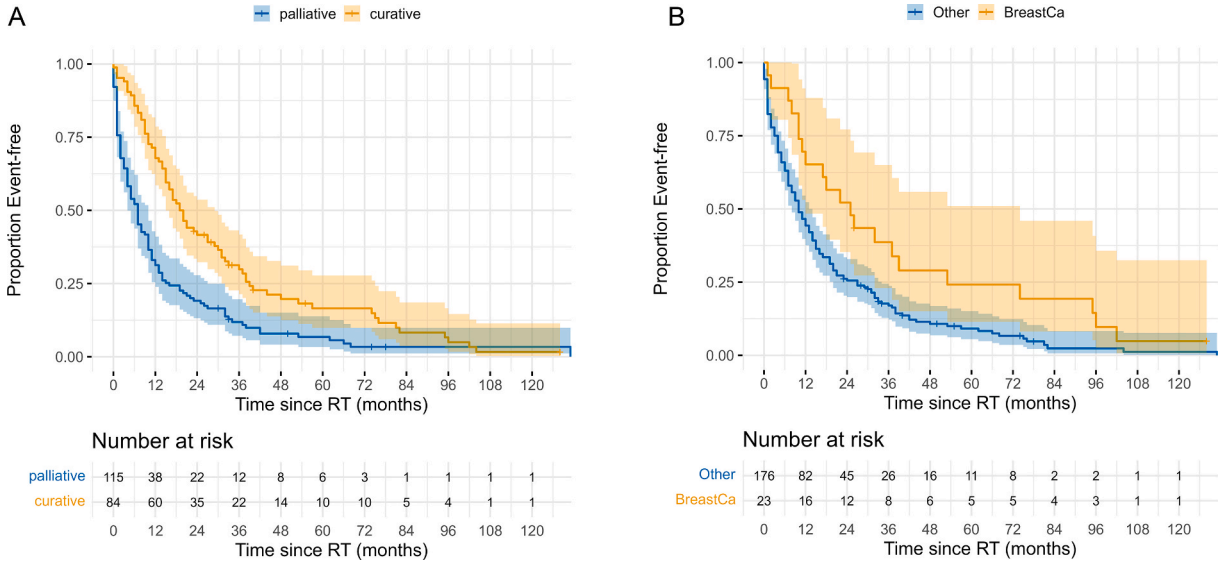

Fig. 1. Kaplan Meier curves depicting the survival of patients treated with curative and palliative intent (A) and patients with breast cancer compared to other entities (B).

Table 1
Patient and treatment characteristics.

Treatment	Palliative (n = 115, 58%)	Curative (n = 84, 42%)	Total (n = 199)	
Sex/Age				
male	53 (46.1%)	35 (41.7%)	88 (44.2%)	
female	62 (53.9%)	49 (58.3%)	111 (55.8%)	
median age (IQR)	91.6 (90.7, 93.3)	91.5 (90.7, 92.6)	91.6 (90.1, 93.1)	
Tumor entities				
| skin	20 (17.4%)	25 (29.8%)	45 (22.6%)	
| gynaecological	20 (17.4%)	8 (9.5%)	28 (14.1%)	
| breast	10 (8.7%)	13 (15.3%)	23 (11.6%)	
| prostate	13 (11.3%)	5 (6.0%)	18 (9.0%)	
| lymphoma	6 (5.2%)	8 (9.5%)	14 (7.0%)	
| bladder	8 (7.0%)	4 (4.8%)	12 (6.0%)	
| lung	5 (4.3%)	6 (7.1%)	11 (5.5%)	
| head and neck	5 (4.3%)	5 (6.0%)	10 (5.0%)	
| colorectal carcinoma	8 (7.0%)	2 (2.4%)	10 (5.0%)	
| anus	2 (1.7%)	3 (3.6%)	5 (2.5%)	
| multiple myeloma	3 (2.6%)	1 (1.2%)	4 (2.0%)	
other *1	15 (13.0%)	4 (4.8%)	19 (9.5%)	
Tumor spread				
| localised	57 (53.8%)	67 (90.5%)	124 (68.9%)	
| oligo *2	8 (7.5%)	7 (9.5%)	15 (8.3%)	
| diffuse	41 (38.7%)	0 (0.0%)	41 (22.8%)	
| missing	0	1	1	
NHL/multiple myeloma*3	9	9	18	
Modality *4				
| 3D-conformal RT	43 (37.4%)	33 (39.3%)	76 (38.2%)	
| IMRT or VMAT	72 (62.6%)	51 (60.7%)	123 (61.8%)	
Fractionation *5				
NF-RT	36 (31.3%)	49 (58.3%)	85 (42.7%)	
HF-RT (>2Gy)	49 (43.0%)	26 (30.6%)	75 (37.7%)	
UHF-RT (≥5Gy)	30 (26.3%)	9 (10.6%)	39 (19.6%)	
ACCI Score				
Median (IQR)	4.50 (2.00, 6.00)	3.00 (2.00, 4.00)	4.00 (2.00, 6.00)	
ACCI ≤ 4	57 (49.6%)	64 (76.2%)	121 (60.8%)	
ACCI > 4	58 (50.4%)	20 (23.8%)	78 (39.2%)	
ECOG Status	67	40	107	
ECOG 0–1	18 (26.9)	17 (42.5%)	35 (32.7%)	
ECOG > 1	49 (73.1%)	23 (57.5%)	72 (67.3%)	
Toxicity CTCAE v5				
0	38 (40.4%)	32 (39.5%)	70 (40.0%)	
1	38 (40.4%)	30 (37.0%)	68 (38.9%)	
2	13 (13.8%)	13 (16.0%)	26 (14.9%)	
3	3 (3.2%)	5 (6.2%)	8 (4.6%)	
4	0 (0.0%)	0 (0.0%)	0 (0.0%)	
5	2 (2.1%)	1 (1.2%)	3 (1.7%)	
Missing	21	3	24	
Median survival (months)*6	7	19	11	
				Med. surv.
RT completed	98 (85%)	79 (94%)	177 (89%)	13
RT not completed *7	17 (15%)	5 (6%)	22 (11%)	1
Re-Irradiations	distant 28	local 8 (PTV overlap 23–3320 cm^3; cumul. BED_{3Gy} 132–193)*8		

*1 CUP, oesophagus, renal cell carcinoma, carcinoma of upper GI tract, sarcoma, pancreatic cancer, benign (arthritis, n = 1).
*2 up to five metastases in three different organ systems.
*3 Hematologic neoplasms are presented as a separate category and are not included in the localized/metastatic "tumor spread" classification or its denominators.
*4 A time trend in the use of radiotherapy techniques is shown in Supplementary Fig. S3.
*5 Trends over time in fractionation schedules are presented in Supplementary Fig. S4.
*6 Vital status completeness at cut-off (27 Mar 2025): 199/199 (100%); deaths: 186 (93.5%); alive/censored: 13 (6.5%).
*7 Reasons for premature discontinuation of radiotherapy are provided in Supplementary Table S7.
*8 Details of local re-irradiations are listed in Supplementary Table S8.

Table 2
Symptom control after radiotherapy by primary symptom.

Symptom	Patients with Symptom	Symptom Change Data	Improvement Reported
Pain	60	48	31 (65%)
Tumor bleeding	21	21	20 (95%)
Ulceration	19	15	12 (80%)
Neurological*a	8	8	4 (50%)
Oedema	6	5	3 (60%)
Other*b	22	14	11 (79%)
Total	136	111	81 (73%)

*1 incomplete paraplegia, facial nerve paralysis, unsteady gait, root compression syndrome.
*2 obstruction of the urinary tract, superior/inferior vena cava syndrome, swelling, dysphagia.

study on 29 younger gastric cancer patients (50% < 65 years) with a bleeding response proportion of 69% [18]. Notably, in that study age was no predictor for radiation response. Taken together, this suggests that the palliative benefit of RT is preserved in the older age.

Regarding treatment toxicity, RT was generally well tolerated with only 5% experiencing grade 3 toxicity, mostly confined to head, neck, or pelvic regions. However, radiation-related fatal events occurred in 1.7%. Frailty, comorbidity burden, and performance status must be carefully considered, as even minor adverse events can have major clinical consequences in this age group. Patient's expectations on treatment achievement, his/her performance status and social support, as well as comorbidity extend are, amongst others, factors affecting implementation of antineoplastic treatment. If a (comprehensive) geriatric assessment in this age group is of additional value in guiding radiation treatment has not yet been demonstrated in a prospective study.

In light of the very limited life expectancy in the diffusely metastasized nonagenarians, palliative treatment regimens should be as short as possible. Large clinical trials in younger age groups have demonstrated, that HF-RT is non-inferior to NF-RT with comparable or reduced toxicities [19–22]. In our analysis, both HF and UHF schedules were associated with lower odds of moderate-to-high acute toxicity relative to NF-RT – smaller irradiated volumes and lower BED_{3Gy} likely contributed—yet the finding remains clinically meaningful given the need to minimize treatment burden in this population. Despite this favorable toxicity profile, hypofractionated approaches showed a nonsignificant trend toward shorter survival, likely reflecting confounding by indication: HF and UHF RT were preferentially selected for patients with poorer functional status or more advanced disease, in order to give them a longer off-treatment time alive. This is already reflected by the uneven distribution of risk factors for patients receiving (ultra)hypofractionated vs. normofractionated RT.

New insights from this study include the finding that nonagenarians with oligometastatic disease (≤5 metastases) have survival comparable to those without metastases, whereas diffuse metastases were associated with substantially shorter OS. Age-related comorbidities and other causes of death become more prevalent at ≥ 90 years, so a small metastatic burden may contribute minimally to all-cause mortality. These observations suggest that the concept of oligometastases as a solid tumor

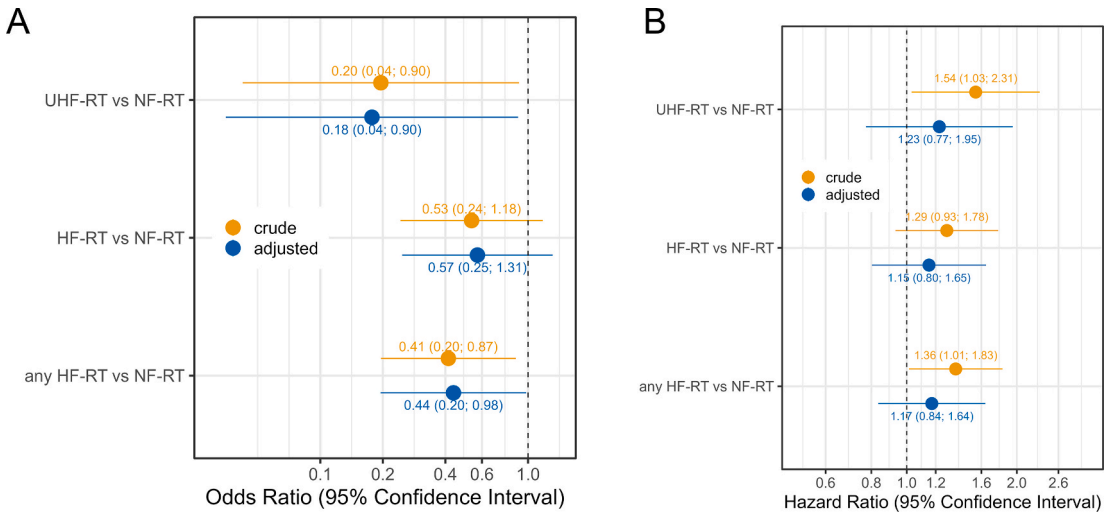

Fig. 2. Crude and adjusted odds ratios for the occurrence of ≥ grade 2 toxicities (A) and hazard ratios for all-cause mortality (B), each with 95% confidence intervals, comparing ultra-hypofractionated (UHF-RT) and hypofractionated radiotherapy (HF-RT) with normofractionated radiotherapy (NF-RT). Models were adjusted for potential confounders. For toxicity models: localized disease status, treatment intent, technique (IMRT/VMAT), and tumor-entity group according to hypofractionation eligibility (bladder, colorectal, skin, lymphoma, breast, prostate, other). For mortality models: the foregoing plus ECOG performance status, Charlson Comorbidity Index category, age at start of radiotherapy, and sex.

stage between locoregional and disseminated disease is also valid for the oldest old. If confirmed by others, metastasis-directed ablative therapy may be feasible in selected nonagenarians and warrant their inclusion in future clinical trials on metastases-directed ablative therapy.

Another novel observation is that nonagenarians with breast cancer exhibited superior survival compared to other malignancies, despite similar median ACCI and ECOG scores. Prior work suggests that elderly patients tend to have more favorable breast cancer characteristics at diagnosis, including anatomical stage and phenotypic characteristics compared to younger patients [23,24]. A Korean registry study [25] found a significantly improved OS in elderly patients (≥75 years) if they received adjuvant endocrine therapy. We emphasize that the signal in our cohort arises from a small, heterogeneous subgroup (n = 23; adjuvant and metastatic) with substantial endocrine therapy use and likely reflects a combination of selection and underlying biology rather than radiotherapy alone. Accordingly, we present this as hypothesis-generating and interpret it with caution; larger, prospectively characterized cohorts are needed to disentangle these factors.

Strengths and limitations

This study represents the largest detailed evaluation of symptom palliation with RT in nonagenarians and identifies subgroups with more favorable survival outcomes. Given that nonagenarians are largely excluded from prospective oncologic trials, the findings provide clinically relevant real-world data for an underrepresented population. The extended study period captured evolving RT techniques and fractionation strategies, and the systematic classification of RT regimens enabled comparative analyses of toxicity and outcomes across fractionation schedules.

Limitations include the retrospective design, with symptom burden and palliation as well as toxicity derived from clinical documentation rather than standardized patient-reported outcomes, introducing potential reporting bias. Comprehensive geriatric assessments were not routinely available, ECOG only documented in later years. The heterogeneity of tumor entities and treatment intent limits entity-specific conclusions, and some subgroup analyses, particularly for breast cancer, oligometastatic disease and ultra-hypofractionated RT, were underpowered. Assessment of outcomes beyond survival is limited by the logistical challenges of patient visits in this age group. Despite adjustment for known confounders, residual confounding by treatment indication cannot be excluded, as hypofractionated regimens were preferentially used in frailer patients or those with advanced disease. These limitations render the study more hypothesis-generating rather than practice-changing.

Conclusions

Radiotherapy can be delivered safely in nonagenarians, with a low frequency of severe toxicity, irrespective of fractionation schedule. As life expectancy, especially in patients treated with palliative intent, is limited and treatment showed a high symptom palliation, hypofractionated treatment schedules are advisable. Patients without metastatic disease and oligometastatic patients, just as those with breast cancer have a comparatively favorable survival outcome, which merits further evaluation.

Use of ChatGPT

Chat GPT was used to assist in improving the clarity and conciseness of selected sections of the manuscript. All content was reviewed and verified by the authors.

CRediT authorship contribution statement

Georg Gruber: Writing – original draft, Supervision, Data curation, Conceptualization. **Christina-Marie Kasassov:** Writing – original draft, Formal analysis, Conceptualization. **Annette Aigner:** Writing – review & editing, Formal analysis. **Christine Track:** Writing – review & editing, Investigation, Data curation. **Lukas Kocik:** Investigation, Data curation. **Elisabeth Silberberger:** Investigation, Data curation. **Michael Geier:** Data curation, Writing – review & editing. **Dalma Nyiri:** Investigation. **Carsten Nieder:** Writing – review & editing. **Hans Geinitz:** Writing – original draft, Project administration, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radonc.2026.111611.

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