

IMPACT OF PELVIC RADIOTHERAPY ON REPRODUCTIVE FERTILITY OUTCOMES

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Abstract

Pelvic radiotherapy is a widely used treatment modality for pelvic malignancies; however, its potential impact on reproductive fertility outcomes remains a critical concern among cancer survivors. This study aimed to assess the effects of pelvic radiotherapy on reproductive fertility outcomes and identify associated clinical, demographic, and treatment-related factors influencing fertility impairment. A quantitative, descriptive-correlational research design was employed, involving 200 cancer patients who had received pelvic radiotherapy. Data were collected through structured questionnaires and medical record reviews and analyzed using SPSS version 26. Descriptive and inferential statistical techniques, including chi-square tests, correlation, and multiple regression analysis, were applied. The findings revealed that a significant proportion of participants experienced fertility impairment, with 76% reporting reduced fertility or complete infertility. A strong negative correlation was observed between radiotherapy dose and fertility outcomes ($r = -0.62, p < 0.05$). Regression analysis indicated that higher radiotherapy doses, older age, and concurrent chemotherapy were significant predictors of poor fertility outcomes, whereas fertility-preservation interventions were associated with improved reproductive outcomes. The study concludes that pelvic radiotherapy has a substantial adverse effect on reproductive fertility, emphasizing the need for early fertility counseling and integration of fertility-preservation strategies into oncology care. The results highlight the importance of balancing oncological effectiveness with reproductive health preservation in cancer treatment planning.

INTRODUCTION

Pelvic radiotherapy is a cornerstone treatment modality for various malignancies affecting the pelvic region, including cervical, endometrial, rectal, anal, bladder, and prostate cancers. Advances in radiation oncology have significantly improved cancer survival rates, resulting in an increasing population of long-term cancer survivors. Consequently, attention has shifted from merely achieving disease control to addressing treatment-related adverse effects that may compromise patients' quality of life. Among these adverse effects, impairment of reproductive fertility has emerged as a critical concern,

particularly for adolescents and young adults who desire future parenthood (Oktay et al., 2018).

Radiotherapy exerts its therapeutic effects through ionizing radiation that damages cellular DNA, leading to tumor cell death. However, normal reproductive tissues within the radiation field are highly susceptible to radiation-induced injury. In females, pelvic radiotherapy can damage ovarian follicles, reduce ovarian reserve, induce premature ovarian insufficiency, and adversely affect uterine structure and function. These effects may result in infertility, menstrual irregularities, miscarriage, preterm birth, and adverse pregnancy outcomes

(Anderson et al., 2020). The severity of reproductive impairment depends on several factors, including radiation dose, treatment volume, patient age, baseline fertility status, and concurrent chemotherapy administration.

The female reproductive system is particularly vulnerable to radiation exposure because ovarian follicles are highly radiosensitive. Research indicates that even low doses of radiation can significantly reduce the ovarian follicular pool, accelerating reproductive aging and shortening the reproductive lifespan (Wallace et al., 2014). Furthermore, radiation-induced uterine fibrosis, vascular insufficiency, and reduced uterine elasticity may impair implantation and fetal development, even when ovarian function is preserved (Larsen et al., 2021). These reproductive complications have profound psychological, social, and economic implications for survivors and their families.

Similarly, male fertility can be adversely affected when pelvic irradiation involves structures associated with reproductive function. Radiation exposure may impair spermatogenesis, reduce sperm quality, induce hormonal imbalances, and contribute to long-term infertility. Although modern radiotherapy techniques have reduced unintended gonadal exposure, concerns regarding reproductive toxicity remain clinically significant, especially among younger patients undergoing curative treatment (Meistrich, 2019).

Recent advances in fertility preservation techniques, including ovarian transposition, oocyte cryopreservation, embryo freezing, ovarian tissue preservation, and sperm banking, have provided promising options for cancer patients before initiating radiotherapy. International guidelines emphasize the importance of fertility counseling and early referral to reproductive specialists as an integral component of comprehensive cancer care (Lambertini et al., 2023). Despite these developments, many patients continue to experience limited access to fertility preservation services due to financial constraints, inadequate awareness, and variations in healthcare infrastructure.

The growing recognition of survivorship-related reproductive issues has generated substantial

scientific interest in evaluating the long-term impact of pelvic radiotherapy on fertility outcomes. However, existing evidence remains heterogeneous regarding the magnitude of fertility impairment, predictors of reproductive recovery, and effectiveness of fertility-preservation interventions. Variations in cancer types, treatment protocols, radiation techniques, and follow-up durations further complicate the interpretation of available findings. Therefore, a comprehensive investigation into the reproductive consequences of pelvic radiotherapy is essential to guide evidence-based clinical decision-making and improve survivorship care.

Understanding the relationship between pelvic radiotherapy and fertility outcomes is particularly important in developing healthcare systems where fertility preservation services remain underdeveloped and survivorship care frameworks are evolving. By identifying the extent and determinants of treatment-related reproductive impairment, healthcare providers can better counsel patients, optimize treatment planning, and implement strategies that balance oncological efficacy with fertility preservation.

Problem Statement

The increasing survival rates among patients receiving pelvic radiotherapy have shifted clinical attention toward long-term treatment-related complications, particularly reproductive fertility impairment. Although pelvic radiotherapy remains an effective treatment modality for numerous pelvic malignancies, its potential to damage reproductive organs poses significant challenges for cancer survivors seeking future parenthood. Existing literature consistently demonstrates an association between radiation exposure and reproductive dysfunction; however, considerable inconsistencies remain regarding the extent, mechanisms, and predictors of fertility impairment across different patient populations. Most available studies focus primarily on cancer control and survival outcomes, while fertility-related consequences often receive limited attention during treatment planning and survivorship management. Furthermore, variations in radiation dosage, treatment

techniques, patient demographics, cancer types, and concurrent therapies contribute to heterogeneous findings and hinder the development of standardized fertility-preservation protocols. In many healthcare settings, fertility counseling remains inadequately integrated into oncology practice, leading to insufficient patient awareness and missed opportunities for fertility preservation before treatment initiation.

A significant research gap exists in comprehensively evaluating reproductive fertility outcomes following pelvic radiotherapy while simultaneously considering clinical, demographic, and treatment-related factors. Moreover, evidence regarding long-term reproductive recovery and the effectiveness of fertility-preservation interventions remains fragmented. Addressing these gaps is essential for developing evidence-based strategies that optimize both cancer treatment outcomes and reproductive health. Therefore, this study seeks to investigate the impact of pelvic radiotherapy on reproductive fertility outcomes and identify key factors influencing fertility preservation among cancer survivors.

Research Questions

1. What is the impact of pelvic radiotherapy on reproductive fertility outcomes among cancer patients?
2. How does pelvic radiotherapy affect ovarian and testicular function following cancer treatment?
3. Which clinical and treatment-related factors significantly influence fertility outcomes after pelvic radiotherapy?
4. What are the long-term reproductive consequences experienced by cancer survivors treated with pelvic radiotherapy?
5. To what extent do fertility-preservation interventions mitigate reproductive impairment associated with pelvic radiotherapy?

Research Objectives

General Objective

To assess the impact of pelvic radiotherapy on reproductive fertility outcomes among cancer survivors.

Specific Objectives

1. To evaluate the effects of pelvic radiotherapy on reproductive fertility outcomes.
2. To examine changes in ovarian and testicular function following pelvic radiotherapy.
3. To identify demographic, clinical, and treatment-related factors associated with fertility impairment.
4. To assess the long-term reproductive consequences of pelvic radiotherapy among cancer survivors.
5. To evaluate the role and effectiveness of fertility-preservation strategies in reducing treatment-related reproductive dysfunction.

Significance of the Study

Theoretical Significance

This study contributes to the growing body of knowledge on cancer survivorship and reproductive medicine by enhancing understanding of the biological and clinical relationship between pelvic radiotherapy and fertility outcomes. The findings will help refine existing theoretical frameworks regarding radiation-induced reproductive toxicity and fertility preservation.

Practical Significance

The study will provide valuable evidence for oncologists, radiation therapists, reproductive specialists, and healthcare practitioners regarding the reproductive consequences of pelvic radiotherapy. The findings will support improved patient counseling, informed decision-making, and individualized treatment planning aimed at preserving fertility without compromising oncological effectiveness.

Policy Significance

The study may inform healthcare policymakers and cancer care organizations in developing guidelines that integrate fertility assessment and preservation into routine oncology practice. The findings can support the formulation of national survivorship programs, fertility-preservation policies, and resource-allocation strategies to improve reproductive health outcomes among cancer survivors.

Literature Review

Pelvic Radiotherapy and Reproductive Fertility Outcomes

Pelvic radiotherapy is widely used in the treatment of gynecological, colorectal, bladder, anal, and prostate cancers. While advances in radiotherapy techniques have substantially improved survival outcomes, concerns regarding treatment-induced infertility remain significant, particularly among adolescents and young adults of reproductive age. Fertility preservation has emerged as an essential component of survivorship care because reproductive health significantly influences psychological well-being, social functioning, and quality of life among cancer survivors (Lambertini et al., 2023).

Radiotherapy causes cellular damage through ionizing radiation-induced DNA breaks and oxidative stress. Although these mechanisms are effective in destroying malignant cells, they also adversely affect normal reproductive tissues located within or adjacent to the radiation field. Several studies have demonstrated that fertility impairment following pelvic radiotherapy is multifactorial, involving direct gonadal damage, endocrine dysfunction, vascular injury, and structural changes in reproductive organs (Anderson et al., 2020).

Effects of Pelvic Radiotherapy on Female Fertility

Female reproductive organs are highly sensitive to radiation exposure. The ovaries contain a finite reserve of primordial follicles that cannot regenerate after destruction. Consequently, radiation-induced follicular depletion may result in diminished ovarian reserve, premature ovarian insufficiency, and infertility (Wallace et al., 2014). Recent evidence suggests that ovarian damage is strongly associated with cumulative radiation dose and patient age at treatment. Younger women generally possess a larger ovarian reserve and may demonstrate greater reproductive resilience than older women. However, even low-to-moderate radiation doses can significantly reduce follicular populations and accelerate reproductive aging (Dolmans & Donnez, 2021).

In addition to ovarian toxicity, pelvic radiotherapy can adversely affect uterine function. Radiation exposure may induce fibrosis, vascular insufficiency, myometrial damage, and reduced uterine elasticity. Such alterations can compromise implantation, fetal growth, and pregnancy maintenance. Women who have undergone pelvic irradiation often experience increased risks of miscarriage, preterm birth, low birth weight, and obstetric complications (Larsen et al., 2021).

Studies involving cervical and endometrial cancer survivors have consistently reported reduced fertility rates following pelvic radiotherapy. The risk becomes particularly pronounced when radiotherapy is combined with chemotherapy, as concurrent treatment modalities may produce synergistic reproductive toxicity (Peccatori et al., 2022).

Effects of Pelvic Radiotherapy on Male Fertility

Although female fertility outcomes have received greater research attention, male reproductive health is similarly vulnerable to radiation-induced injury. Testicular germ cells are among the most radiosensitive cells in the human body. Exposure to pelvic radiation may impair spermatogenesis, reduce sperm concentration and motility, and increase sperm DNA fragmentation (Meistrich, 2019).

Research indicates that fertility impairment in males depends on radiation dose, treatment duration, and the extent of gonadal exposure. Temporary infertility may occur following lower radiation doses, whereas higher cumulative doses can result in permanent azoospermia and irreversible reproductive dysfunction (Howell & Shalet, 2020).

Furthermore, pelvic radiotherapy may affect endocrine regulation through damage to Leydig cells, resulting in reduced testosterone production and hormonal imbalance. Such disruptions can negatively influence sexual health, reproductive function, and overall quality of life among male cancer survivors (Miah et al., 2022).

Long-Term Reproductive Consequences of Pelvic Radiotherapy

The long-term reproductive consequences of pelvic radiotherapy extend beyond infertility. Survivors frequently experience premature menopause, sexual dysfunction, altered reproductive hormone profiles, and psychosocial distress associated with compromised fertility potential. These effects may persist for decades after treatment completion (Anderson et al., 2020).

Recent survivorship studies have highlighted substantial disparities in reproductive outcomes among different cancer populations. Factors such as treatment intensity, radiation technique, age at diagnosis, baseline fertility status, and access to fertility-preservation services significantly influence long-term reproductive health (Lambertini et al., 2023).

Emerging evidence also suggests that fertility-related concerns remain inadequately addressed during oncology consultations. Many patients report insufficient counseling regarding reproductive risks before initiating radiotherapy, leading to reduced utilization of fertility-preservation strategies and increased post-treatment regret (Oktay et al., 2018).

Fertility Preservation Strategies

Growing awareness of treatment-related infertility has stimulated the development of fertility-preservation interventions. Current options include ovarian transposition, embryo cryopreservation, oocyte freezing, ovarian tissue cryopreservation, sperm banking, and testicular tissue preservation (Lambertini et al., 2023).

Among women, oocyte and embryo cryopreservation are considered established fertility-preservation methods. Ovarian tissue cryopreservation has also gained recognition as an effective strategy, particularly for patients requiring immediate cancer treatment. In men, sperm cryopreservation remains the most widely recommended and successful fertility-preservation approach (Oktay et al., 2018).

Recent studies have demonstrated favorable reproductive outcomes among patients utilizing fertility-preservation interventions before

treatment. Nevertheless, access remains uneven due to financial barriers, limited healthcare infrastructure, cultural factors, and inadequate provider awareness, particularly in developing countries (Peccatori et al., 2022).

Modern Radiotherapy Techniques and Fertility Outcomes

Technological advancements in radiation oncology have facilitated the development of fertility-sparing treatment approaches. Techniques such as Intensity-Modulated Radiation Therapy (IMRT), Image-Guided Radiation Therapy (IGRT), Volumetric Modulated Arc Therapy (VMAT), and proton therapy allow for more precise targeting of tumors while minimizing radiation exposure to surrounding reproductive tissues (Murray et al., 2023).

Several recent studies have reported reduced gonadal toxicity and improved reproductive outcomes with advanced radiation techniques compared to conventional radiotherapy. However, long-term evidence remains limited, and further investigation is required to establish optimal treatment protocols that balance oncological efficacy with fertility preservation (Murray et al., 2023).

Research Gap

Despite substantial progress in understanding radiation-induced reproductive toxicity, several important gaps remain in the literature. First, existing studies predominantly focus on specific cancer populations rather than providing comprehensive assessments across diverse pelvic malignancies. Second, inconsistencies persist regarding dose-response relationships and predictors of fertility recovery following treatment. Third, limited evidence exists concerning long-term fertility outcomes among survivors treated with modern radiotherapy techniques.

Additionally, most research has been conducted in high-income countries where fertility-preservation services are relatively accessible. Evidence from developing healthcare systems remains scarce, limiting the generalizability of findings. Furthermore, studies integrating biological, clinical, psychosocial, and healthcare-system

determinants of fertility outcomes remain limited. These gaps highlight the need for comprehensive investigations examining the impact of pelvic radiotherapy on reproductive fertility outcomes and the effectiveness of fertility-preservation strategies among cancer survivors.

Underpinning Theory

Life Course Theory

Theory Overview

Life Course Theory, originally developed by Glen H. Elder Jr. (1974), provides a valuable framework for understanding how significant life events influence individual development and future outcomes across different stages of life. The theory emphasizes that experiences occurring during critical developmental periods can have long-lasting consequences on health, social functioning, psychological well-being, and life trajectories.

According to Life Course Theory, health-related events are not isolated occurrences but rather interconnected experiences that shape subsequent life opportunities and outcomes. Major life transitions, such as illness, medical treatment, marriage, parenthood, and aging, can significantly alter an individual's developmental pathway.

Applicability to the Study

Life Course Theory is highly relevant to the study of pelvic radiotherapy and reproductive fertility outcomes because cancer diagnosis and treatment represent major life events that may permanently influence an individual's reproductive trajectory. Pelvic radiotherapy administered during adolescence or reproductive adulthood can disrupt normal reproductive development by impairing ovarian reserve, spermatogenesis, hormonal function, and reproductive capacity. These biological changes may subsequently affect important life-course transitions such as family formation, parenthood, marital relationships, and psychosocial well-being.

The theory further explains how fertility impairment resulting from radiotherapy may produce cumulative long-term effects extending beyond physical health to social, emotional, and economic dimensions of life. For example,

treatment-induced infertility may influence future family planning decisions, psychological adjustment, relationship satisfaction, and overall quality of life among cancer survivors.

Moreover, Life Course Theory supports the importance of early fertility counseling and fertility-preservation interventions before treatment initiation. By addressing reproductive risks at a critical life stage, healthcare providers can potentially modify future life trajectories and improve long-term survivorship outcomes.

Theoretical Proposition

Based on Life Course Theory, exposure to pelvic radiotherapy during reproductive years is expected to influence future fertility outcomes, reproductive functioning, and subsequent life-course transitions. The severity of these effects is likely moderated by factors such as age at treatment, radiation dose, fertility-preservation measures, and access to survivorship care services.

Hypotheses

H1: Pelvic radiotherapy significantly reduces reproductive fertility outcomes among cancer survivors.

H2: Higher doses of pelvic radiotherapy are associated with greater impairment of reproductive fertility.

H3: Pelvic radiotherapy significantly decreases ovarian function among female cancer survivors.

H4: Pelvic radiotherapy significantly decreases testicular function among male cancer survivors.

H5: Longer exposure to pelvic radiotherapy is associated with poorer fertility outcomes.

H6: Cancer survivors who undergo fertility-preservation interventions experience better fertility outcomes than those who do not.

H7: Advanced radiotherapy techniques are associated with lower fertility impairment compared to conventional radiotherapy techniques.

H8: Younger patients undergoing pelvic radiotherapy experience better post-treatment fertility outcomes than older patients.

Methodology

Research Design

This study employed a quantitative, descriptive-correlational research design. The design was selected to examine the relationship between pelvic radiotherapy and reproductive fertility outcomes among cancer survivors, as well as to identify associated clinical and treatment-related factors.

Population

The target population comprised male and female cancer patients who had received pelvic radiotherapy for malignancies such as cervical, uterine, rectal, bladder, anal, and prostate cancers. The study population also included long-term cancer survivors within reproductive age groups attending oncology follow-up clinics.

Sampling Technique

A purposive sampling technique was used to select participants who met the inclusion criteria. This technique was considered appropriate because only patients with a confirmed history of pelvic radiotherapy and available reproductive health data were included in the study.

Sample Size

A total sample size of 200 participants was determined based on feasibility, availability of eligible patients, and previous similar studies in oncology survivorship research. The sample included both male and female respondents to ensure gender representation in fertility outcome assessment.

Data Collection Procedures

Data were collected through oncology outpatient departments and follow-up clinics of selected tertiary care hospitals. After obtaining ethical approval and informed consent from participants, data were gathered using structured questionnaires and medical record reviews. Participants were interviewed regarding reproductive history, fertility concerns, and post-treatment reproductive outcomes. Clinical data, including radiation dose, treatment duration,

cancer type, and chemotherapy use, were extracted from hospital records.

Instruments/Measures

A structured questionnaire was developed based on validated tools from previous fertility and oncology survivorship studies. The instrument consisted of four sections:

1. Socio-demographic information (age, gender, marital status, and socioeconomic status)
2. Clinical characteristics (cancer type, stage, treatment modalities, radiation dose)
3. Reproductive health outcomes (menstrual history, pregnancy outcomes, sperm parameters, fertility status)
4. Fertility-related quality of life and counseling history

In addition, a standardized clinical data extraction sheet was used to obtain treatment-related information from medical records.

Reliability and Validity

Content validity of the research instrument was ensured through expert review by oncologists, reproductive health specialists, and research methodologists. Necessary modifications were made based on their feedback to improve clarity and relevance.

A pilot study was conducted on 20 participants who were not included in the final sample to test the clarity and feasibility of the instrument. The reliability of the questionnaire was assessed using Cronbach's alpha, which yielded a value of 0.82, indicating acceptable internal consistency.

Construct validity was ensured by aligning questionnaire items with established literature and validated measures used in prior studies on fertility and cancer survivorship. Additionally, triangulation of self-reported data with clinical records enhanced the overall validity of the findings.

Data Analysis and Interpretation

Data Analysis

The collected data were analyzed using SPSS version 26. Both descriptive and inferential statistical techniques were applied. Descriptive statistics (frequency, percentage, mean, and

standard deviation) were used to summarize demographic characteristics, clinical profiles, and fertility outcomes. Inferential statistics, including chi-square test, independent sample t-test, Pearson correlation, and multiple regression analysis, were

used to examine relationships between pelvic radiotherapy and fertility outcomes. A significance level of $p < 0.05$ was considered statistically significant.

Table 1: Demographic Characteristics of Respondents (n = 200)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	92	46.0
	Female	108	54.0
Age Group	18-30 years	52	26.0
	31-45 years	88	44.0
	46-60 years	44	22.0
	>60 years	16	8.0
Marital Status	Married	138	69.0
	Single	62	31.0

The results indicated that a slightly higher proportion of respondents were female (54%) compared to males (46%). The majority of participants were between 31-45 years (44%),

representing the most reproductively active age group. Most respondents were married (69%), indicating a high relevance of fertility outcomes in this population.

Table 2: Clinical Characteristics of Respondents

Variable	Category	Frequency (n)	Percentage (%)
Cancer Type	Cervical	74	37.0
	Prostate	48	24.0
	Bladder	36	18.0
	Rectal	28	14.0
	Anal	14	7.0
Radiotherapy Dose	<50 Gy	64	32.0
	50-70 Gy	98	49.0
	>70 Gy	38	19.0

Cervical cancer was the most common malignancy (37%), followed by prostate cancer (24%). The majority of patients received 50-70 Gy radiation dose (49%), indicating standard radical treatment

protocols. A considerable proportion received higher doses (>70 Gy), which are clinically associated with increased toxicity risk.

Table 3: Fertility Outcomes After Pelvic Radiotherapy

Fertility Outcome	Frequency (n)	Percentage (%)
Normal fertility retained	48	24.0
Reduced fertility	86	43.0
Complete infertility	66	33.0

The results demonstrated that only 24% of patients retained normal fertility after treatment. A significant proportion (76%) experienced either

reduced fertility or complete infertility, indicating a strong negative impact of pelvic radiotherapy on reproductive health outcomes.

Table 4: Correlation Between Radiotherapy Dose and Fertility Outcomes

Variable	r-value	p-value
Radiotherapy dose vs fertility outcome	-0.62	0.001

A strong negative correlation ($r = -0.62$, $p = 0.001$) was found between radiotherapy dose and fertility outcomes, indicating that higher radiation doses

were significantly associated with poorer fertility outcomes among cancer survivors.

Table 5: Regression Analysis Predicting Fertility Outcomes

Predictor Variable	Beta (β)	t-value	p-value
Radiotherapy dose	-0.41	-5.62	0.000
Age	-0.28	-3.94	0.001
Chemotherapy use	-0.33	-4.88	0.000
Fertility preservation	+0.36	5.21	0.000

Regression analysis revealed that radiotherapy dose, age, and chemotherapy use were significant negative predictors of fertility outcomes. Fertility preservation interventions showed a positive and significant effect, indicating improved reproductive outcomes among patients who received such interventions.

and fertility status, suggesting a dose-dependent effect on reproductive impairment. Additionally, older age and combined chemotherapy further exacerbated fertility decline, highlighting the multifactorial nature of treatment-induced reproductive toxicity.

Overall Interpretation of Findings

The findings of the study clearly demonstrated that pelvic radiotherapy has a substantial adverse impact on reproductive fertility outcomes among cancer survivors. A large proportion of patients experienced reduced fertility or complete infertility following treatment, particularly those exposed to higher radiation doses and concurrent chemotherapy.

Conversely, patients who received fertility-preservation interventions demonstrated comparatively better reproductive outcomes, emphasizing the clinical importance of early fertility counseling and intervention prior to treatment initiation.

The statistical analysis confirmed a significant negative relationship between radiotherapy dose

Overall, the results underscore the need for integrating fertility preservation strategies into standard oncology care to minimize long-term reproductive complications among cancer survivors.

Discussion

The findings of this study demonstrated that pelvic radiotherapy has a significant negative impact on reproductive fertility outcomes, with 76% of participants experiencing reduced fertility or complete infertility. These results are consistent with previous research indicating that pelvic irradiation is strongly associated with gonadal damage, endocrine disruption, and reduced reproductive capacity (Wallace et al., 2014; Larsen et al., 2021). The observed dose-dependent relationship between radiotherapy exposure and fertility impairment aligns with existing literature that identifies radiation dose as a primary determinant of ovarian and testicular toxicity (Meistrich, 2019).

The current study also revealed that higher radiotherapy doses, older age, and concurrent chemotherapy significantly worsened fertility outcomes. These findings are consistent with Anderson et al. (2020), who reported that combined modality treatment increases reproductive toxicity due to synergistic cellular damage. Similarly, Oktay et al. (2018) emphasized that patient age is a critical predictor of fertility decline, as ovarian reserve and spermatogenic capacity decrease naturally with age, thereby amplifying radiation-induced damage.

The positive association between fertility-preservation interventions and improved reproductive outcomes supports the findings of Lambertini et al. (2023), who highlighted the effectiveness of oocyte cryopreservation, sperm banking, and ovarian tissue preservation in maintaining fertility potential among cancer patients. However, the present findings suggest that such interventions remain underutilized, particularly in resource-limited settings, reflecting disparities in access to reproductive healthcare services.

From a theoretical perspective, the findings strongly support Life Course Theory, which posits that health events occurring during critical life stages can have long-term consequences on individual trajectories. Pelvic radiotherapy during reproductive years disrupts biological reproductive potential and subsequently influences key life transitions such as marriage, family formation,

and psychosocial well-being. The observed long-term fertility impairment reinforces the concept that cancer treatment is not an isolated event but a life-altering experience with enduring developmental implications.

Conclusion

The study concluded that pelvic radiotherapy significantly impairs reproductive fertility outcomes among cancer survivors. A substantial proportion of patients experienced reduced fertility or infertility, particularly those exposed to higher radiation doses and concurrent chemotherapy. Age and treatment intensity were identified as significant predictors of fertility outcomes, while fertility-preservation interventions demonstrated a protective effect. Overall, the findings highlight the critical need for integrating fertility considerations into oncology treatment planning.

Implications

Theoretical Implications

This study contributes to Life Course Theory by empirically demonstrating how cancer treatment during reproductive years alters long-term biological and social trajectories. It extends theoretical understanding of treatment-related fertility disruption as a life-course transition with enduring consequences.

Managerial (Healthcare Management) Implications

Hospital administrators and oncology departments should develop structured fertility counseling protocols and integrate reproductive specialists into cancer care teams. Effective coordination between oncology and reproductive medicine services is essential for comprehensive patient management.

Practical Implications

Clinicians should routinely discuss fertility risks with patients prior to initiating pelvic radiotherapy. Fertility-preservation options should be offered early, especially for young and reproductive-age patients. Treatment planning

should also consider dose minimization strategies where clinically feasible.

Policy Implications

Health policymakers should establish national guidelines mandating fertility counseling before radiotherapy. Public healthcare systems should also subsidize fertility-preservation procedures to ensure equitable access, particularly in low-resource settings.

Recommendations

1. Fertility counseling should be made a mandatory component of pre-radiotherapy evaluation for all reproductive-age patients.
2. Oncologists should refer patients early to reproductive specialists for fertility-preservation planning.
3. Healthcare institutions should invest in advanced radiotherapy techniques (e.g., IMRT, IGRT) to reduce gonadal exposure.
4. National health policies should include funding mechanisms for fertility preservation services.
5. Long-term survivorship clinics should incorporate routine reproductive health monitoring.

Limitations and Future Directions

Limitations

This study had several limitations. First, it was conducted in selected tertiary care hospitals, which may limit generalizability to other healthcare settings. Second, the use of self-reported fertility outcomes may introduce recall bias. Third, the cross-sectional design restricts the ability to establish causal relationships between radiotherapy and fertility impairment. Finally, hormonal assays and detailed reproductive biomarkers were not included due to resource constraints.

Future Directions

Future research should adopt longitudinal cohort designs to assess long-term reproductive recovery after pelvic radiotherapy. Studies incorporating hormonal profiling and advanced reproductive biomarkers are recommended for more precise

assessment of gonadal function. Comparative studies between conventional and advanced radiotherapy techniques are also needed. Additionally, future research should explore psychosocial and quality-of-life outcomes related to fertility impairment among cancer survivors.

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