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# Gonad Dose Assessment of Patients Undergoing Pelvic Radiotherapy

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**Abstract**

Introduction: Radiotherapy can impact on patients' reproductive organs and fertility. This study aims (i) to assess whether the doses to the gonads of 70 patients met the tolerance doses used in radiotherapy planning; (ii) to compare Three-Dimensional Conformal Radiotherapy (3DCRT) with Volumetric Modulated Arc Therapy (VMAT) techniques; and (iii) to verify if ovarian transposition reduces the dose to the ovaries. Methods: A retrospective analysis of 70 patients aged 45 or under who underwent pelvic radiotherapy between 2014 and 2023 in a radiotherapy department was carried out. The dose constraints considered were derived from the Dose-Volume Constraints for Organs at Risk in Radiotherapy project. Results: The average number of children of all the patients in the study was 1.25 and the standard deviation was 1.40. No statistically significant differences were detected regarding the doses to the left and right gonads between 3DCRT and VMAT ($p > 0.05$). There were statistically significant differences between female patients who underwent ovarian transposition and those who did not undergo ovarian transposition regarding the maximum and medium doses in both right and left ovaries ($p < 0.05$), with a dose reduction that could reduce doses by an average of up to 39 Gy. Conclusions: In the total sample, 58.6% of patients were treated with VMAT, only 18.6% met the maximum dose limits, and 22.9% met the average dose constraints. Only five women underwent ovarian transposition, which proved effective in meeting dose constraints and significantly reducing the dose to the ovaries.

**Keywords:** gonad dose; ovarian transposition; pelvic radiotherapy



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## 1. Introduction

Cancer is a major societal, public health, and economic problem in the 21st century and is responsible for three in ten global premature deaths caused from noncommunicable diseases in those aged 30–69 years [1]. Every year, more than 135,000 people under 45 years of age are diagnosed with cancer [2]. However, with the improvement in the diagnosis and treatment of the disease, more than 70% of cancer patients under 45 will survive beyond five years after treatment [2]. For this reason, the long-term quality of life for survivors is crucial, especially regarding fertility issues [3]. Combined with the current trend of delaying motherhood [4] and the increasingly early diagnosis of cancer, there is an increasing number of cancer survivors of reproductive age for whom both the cure and quality of life are critical [5].

The impact of oncological treatments on the fertility of patients positions oncofertility as an emerging clinical area of multidisciplinary intervention that should be discussed with patients as early as diagnosis [6,7]. On one hand, the diagnosis of cancer can lead to some emotional fragility, and several studies indicate thar cancer survivors exhibit greater motivation for parenting compared with healthy individuals. On the other hand, patients who have had the opportunity to previously discuss fertility preservation (FP) with a multidisciplinary team, such as a surgeon, oncologist, radiation oncologist, and fertility specialist, tend to experience a better quality of life [8].

Despite these indicators, many patients still do not discuss FP before starting cancer therapy due to factors such as lack of information, prioritization of the cure, unavailability of healthcare professionals or resources, the absence of a partner, or having pre-existing children; therefore, raising awareness among patients and healthcare professionals about the importance of this issue is essential [9,10].

Radiotherapy is widely used in the treatment of several neoplasms, either as a single or concomitant therapy. In the case of pelvic radiotherapy, the risk of infertility can be high as a result of direct ovarian gonadotoxicity or uterine functional alterations in women [11]. In the case of men, it is due to the direct gonadotoxicity of the testicle or alterations in ejaculatory function or sexual dysfunction [11,12].

Selecting the optimal fertility preservation option for pelvic cancer patients depends on factors such as age, marital status, economic situation, cancer type and stage, treatment plan, and timeframe for initiating therapy [13].

In addition to the most commonly used techniques like the cryopreservation of oocytes, sperm, embryos, and ovarian and testicular tissue, women undergoing pelvic radiotherapy can opt for ovarian transposition [14]. Ovarian transposition, also called oophoropexy, is a surgical maneuver used to prevent damage to the ovaries during radiation therapy. Before treatment begins, one or both ovaries and the fallopian tubes are separated from the uterus and attached to the wall of the abdomen away from where the radiation will be given [15]. According to the literature, this technique allows the successful preservation of hormonal function in 70–93% of cases and the ovarian dose is reduced by three to four times compared with leaving the ovaries in their anatomical position. Ovarian transposition may be useful for women who want to have children after radiation therapy [15,16]. Performing oophoropexy prior to radiotherapy may help to preserve ovarian hormonal function for a certain period and fertility may still be achievable through surrogate pregnancy. When successful, ovarian transposition can enhance overall health and wellbeing, expand reproductive options, and potentially improve the quality of life in patients with cervical and other gynecologic cancers [17]. In a recent study of 18 patients who underwent ovarian transposition before radiotherapy, the authors suggest that in patients who wish to preserve fertility or hormonal function, more aggressive strategies for ovary-sparing approaches may be justified [18].

For photon radiotherapy treatments, Three-Dimensional Conformal Radiotherapy (3DCRT), Intensity-Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) techniques can be used [19]. Although there have been no significant differences in survival rates, several studies have demonstrated the advantages of using the VMAT technique to significantly reduce doses to organs at risk, particularly the gonads, as well as reduce late toxicity in the small intestine, consequently decreasing late morbidity [20,21].

This study was conducted in a radiotherapy department with the following aims: (i) to assess whether the doses to the gonads of the 70 patients met the tolerance doses used in radiotherapy planning, (ii) to compare the 3DCRT technique with the VMAT technique, and (iii) to determine if ovarian transposition reduces the dose to the ovaries.

The literature on gonadal dose assessment is scarce, particularly when evaluating doses to the gonads and even more so with the use of the ovarian transposition technique. This study stands out for considering the segmented gonads as organs at risk in 70 real patients under the age of 45.

## 2. Methods

Given the retrospective nature of this study, special attention was paid to minimize selection bias and ensure data consistency. The inclusion criteria were (i) age $\leq$ 45 years at the time of treatment; (ii) diagnosis of rectal or gynecological tumors; (iii) treatment with external beam radiotherapy between 2014 and 2023; (iv) the use of 3DCRT, IMRT, and VMAT techniques; and (v) availability of complete planning using Computed Tomography (CT) images and medical records in the institutional systems. The study aimed to reflect real-world clinical practice by including all eligible patients during the study period, thus enhancing external validity and reducing the risk of selection bias. No patients were excluded.

For all patients, the clinical history, diagnosis, treatment plan, and discussion of FP or family planning were analyzed using the SClínico Hospitalar Evolutionary Information System, version 2.8, developed by the Shared Services of the Ministry of Health. The technique, positioning, and fractionation of the radiation treatment were collected using the ARIA Oncology Information System, version 16.1, from Varian Medical Systems (Palo Alto, CA, USA). Despite being very radiosensitive, the ovaries are not typically considered to be organs at risk in pelvic radiotherapy. However, with improvements in irradiation techniques and the possibility of using Magnetic Resonance Imaging (MRI), their contouring is recommended, mainly in younger patients [22]. According to the literature, the appearance of the ovaries changes with age and the patient's hormonal status. During reproductive years, ovarian identification is facilitated by the presence of follicles but this becomes more challenging as patients age [23]. The patients did not have their gonads contoured and the automatic segmentation systems currently available in the department do not include contours for the ovaries or testicles. For this reason, it was necessary for each patient's planning CT scan to be manually contoured using Eclipse Treatment Planning Software, version 16.1, from Varian Medical Systems (Palo Alto, CA, USA). To reduce interobserver variability in the dose assessment, all gonadal delineations were manually performed by a radiation oncologist and a radiation therapist, both experienced in pelvic anatomy, and supported by MRI fusion [24]. Following this, the maximum and mean doses to both the right and left ovaries, as well as the testicles, were calculated and analyzed. The dose constraints taken into account in our department were from the Dose-Volume Constraints for Organs at Risk in Radiotherapy (CORSAIR): An All-in-One Multicenter–Multidisciplinary Practical Summary project, including radiation oncologists, medical physicists, and radiologists, as shown in Table 1 [25].

The statistical analysis was performed using IBM SPSS Statistics software, version 29.0.2, for Microsoft Windows. Results were considered to be statistically significant at a $p$-value of <0.05. To test the data normality, the Shapiro–Wilk test was used. The Wilcoxon test was used to compare the maximum and mean doses between the left and right testicles, as well as the left and right ovaries, because the normality assumption was not met. The Mann–Whitney test was used to compare the 3DCRT and VMAT techniques and to evaluate differences between females who underwent ovarian transposition and those who did not.

**Table 1.** Dose constraints from the CORSAIR project [25].

| Dose Limits | Maximum Dose | Mean Dose |
|---|---|---|
| Testicles | <6 Gy | <5 Gy |
| Ovaries | $V_{7.5\ Gy} < 26\%$ * | <8.8 Gy |

Gy—gray. * The volume at 7.5 Gy should be less than 26%.

## 3. Results

Of the 70 patients studied aged 45 years or younger who underwent pelvic radiotherapy between 2014 and 2023, 12 were male patients with rectal tumors, 18 were female patients with rectal tumors, and 40 were female patients with gynecological tumors. The average age of all study patients was 38.76 years, with a standard deviation of 6. The average number of children before treatment was 1.25 and the standard deviation was 1.40. Of these 70 patients, 58.6% of patients were treated with the VMAT technique. Since 2020, all patients in the study were treated with the VMAT technique. Despite this, only 18.6% of patients met the maximum dose limits and 22.9% met the mean dose limits for the testicles and ovaries. Across the entire sample, only 5 female patients underwent ovarian transposition. The results are presented separately for male patients, female patients with rectal tumors, and female patients with gynecological tumors.

Male patients with rectal tumors

The characteristics of the male patients with rectal tumors are summarized in Table 2. All patients received 50.40 Gy in 28 fractions in the prone position. Of these, 4 patients were treated using the 3DCRT technique and 8 were treated with the VMAT technique. The average age of the patients was 38.75 years, with a standard deviation of 5. The average number of children before treatment was 0.56, with a standard deviation of 0.88.

**Table 2.** Characterization of the sample males with rectal tumors.

| Total Patients | Average Age | Minimum Age | Maximum Age | Average Children | Dose | Position | 3DCRT | VMAT |
|---|---|---|---|---|---|---|---|---|
| 12 | 38.75 | 32 | 45 | 0.56 | 50.40 Gy | Prone | 4 | 8 |

Table 3 summarizes the irradiation technique as well as the maximum and mean doses delivered to each patient's right and left testicles. According to the CORSAIR project, only 50% of patients complied with the maximum dose limit for the testicles (<6 Gy), with one patient meeting the limit solely for the left testicle. When evaluating the mean dose, 66.70% of patients met the dose limit for both testicles, while one patient met the limit only for the left testicle.

No statistically significant differences were observed between the doses delivered to the left and right testicles ($p > 0.05$). However, significant differences were detected between the maximum and mean doses ($p < 0.05$), with the maximum dose being significantly higher, as expected. Furthermore, no statistically significant differences were observed between the VMAT and 3DCRT techniques in terms of the maximum and mean doses delivered to either the left or right testicles ($p > 0.05$).

**Table 3.** Technique and maximum and mean doses in Gy for the right and left testicles of males with rectal tumors.

| Patient | Technique | $D_{max}$ TestR | $D_{max}$ TestL | $D_{max}$ < 6 Gy | $D_{mean}$ TestR | $D_{mean}$ TestL | $D_{mean}$ < 5 Gy |
|---|---|---|---|---|---|---|---|
| 1 | VMAT | 1.80 | 1.77 | Complies | 0.71 | 0.71 | Complies |
| 2 | VMAT | 0.93 | 0.94 | Complies | 0.65 | 0.65 | Complies |
| 3 | VMAT | 13.79 | 14.25 | Does not comply | 4.08 | 3.53 | Complies |
| 4 | VMAT | 0.59 | 0.40 | Complies | 0.35 | 0.28 | Complies |
| 5 | VMAT | 17.52 | 19.46 | Does not comply | 11.24 | 11.78 | Does not comply |
| 6 | VMAT | 6.50 | 4.30 | Left complies | 2.30 | 2.10 | Left complies |
| 7 | VMAT | 0.75 | 0.75 | Complies | 0.41 | 0.36 | Complies |
| 8 | 3DCRT | 0.92 | 0.91 | Complies | 0.20 | 0.20 | Complies |
| 9 | VMAT | 0.68 | 0.71 | Complies | 0.41 | 0.44 | Complies |
| 10 | 3DCRT | 13.80 | 14.10 | Does not comply | 3.70 | 4.05 | Complies |
| 11 | 3DCRT | 17.20 | 16.90 | Does not comply | 12.30 | 9.26 | Does not comply |
| 12 | 3DCRT | 10.90 | 11.30 | Does not comply | 7.60 | 9.80 | Does not comply |
| Mean/Std. Deviation | | 7.12/7.03 | 7.15/7.42 | | 3.66/4.38 | 3.60/4.26 | |

Abbreviations: $D_{max}$—maximum dose limit; $D_{mean}$—mean dose limit; TestR—right testicle; TestL—left testicle; Std. Deviation—standard deviation.

It should be noted that no distinction was made between high, medium, or low rectal cancer, although the position of the treatment volume relative to the testicles could influence proximity and thus the likelihood of meeting the dose limit. The distance from the position of the tumor to the testicles was measured in the same way for each patient, in the sagittal plane. No differences of more than 2 cm were observed, so this difference had no statistically significant impact on the dose administered to the testicles.

Female patients with rectal tumors

All patients were treated with 50.40 Gy in 28 fractions in the prone position, except for one patient who was treated in the dorsal position due to uterine invasion, receiving 25 Gy in 5 fractions, as detailed in Table 4. The 3DCRT technique was used in 12 patients, while VMAT was employed for 6 patients. The average age of the patients was 38.83 years, with a standard deviation of 6.38. The average number of children before treatment was 0.94, with a standard deviation of 1.

**Table 4.** Characterization of the sample females with rectal tumors.

| Total Patients | Average Age | Minimum Age | Maximum Age | Average Children | Dose | Position | 3DCRT | VMAT |
|---|---|---|---|---|---|---|---|---|
| 18 | 38.83 | 22 | 45 | 0.94 | 50.40 Gy | Prone | 12 | 6 |

Table 5 presents the technique as well as the maximum and mean doses delivered to the right and left ovaries for each female patient. No patient met the maximum dose limit ($V_{7.5Gy}$ < 26%), suggesting that the volume receiving 7.50 Gy should have been less than 26%, as well as the mean dose limit (<8.80 Gy), as defined by the CORSAIR project [25]. Additionally, no statistically significant differences were detected between the doses to the left and right ovaries ($p > 0.05$).

However, statistically significant differences were observed between the maximum and mean doses for both the left ovary ($z = -3.724$; $p < 0.001$) and the right ovary ($z = -3.724$; $p < 0.001$), with the maximum dose being significantly higher in both cases. No statistically significant differences were found between the VMAT and 3DCRT techniques regarding the maximum and mean doses delivered to the left and right ovaries ($p > 0.05$).

**Table 5.** Technique and maximum and mean doses in Gy for the right and left ovaries of females with rectal tumors.

| Patient | Technique | $D_{max}$ OvaR | $D_{max}$ OvaL | $V_{7.5\ Gy}$ < 26% | $D_{mean}$ OvaR | $D_{mean}$ OvaL | $D_{mean}$ < 8.8 Gy |
|---|---|---|---|---|---|---|---|
| 1 | VMAT | 53.79 | 52.76 | Does not comply | 47.93 | 50.43 | Does not comply |
| 2 * | VMAT | 52.69 | 53.23 | Does not comply | 48.75 | 43.02 | Does not comply |
| 3 | VMAT | 52.42 | 52.12 | Does not comply | 47.55 | 51.65 | Does not comply |
| 4 | VMAT | 25.63 | 26.17 | Does not comply | 24.85 | 25.36 | Does not comply |
| 5 | 3DCRT | 51.56 | 34.26 | Does not comply | 48.39 | 21.81 | Does not comply |
| 6 | 3DCRT | 51.80 | 51.54 | Does not comply | 50.70 | 49.36 | Does not comply |
| 7 | 3DCRT | 45.23 | 43.53 | Does not comply | 41.83 | 24.84 | Does not comply |
| 8 | 3DCRT | 50.54 | 50.05 | Does not comply | 50.33 | 39.01 | Does not comply |
| 9 | VMAT | 44.71 | 38.50 | Does not comply | 38.67 | 32.26 | Does not comply |
| 10 | VMAT | 51.65 | 52.67 | Does not comply | 50.32 | 50.47 | Does not comply |
| 11 | 3DCRT | 51.08 | 51.40 | Does not comply | 50.74 | 51.05 | Does not comply |
| 12 | 3DCRT | 50.18 | 50.59 | Does not comply | 43.64 | 48.25 | Does not comply |
| 13 | 3DCRT | 51.11 | 51.66 | Does not comply | 47.07 | 46.42 | Does not comply |
| 14 | 3DCRT | 52.18 | 52.12 | Does not comply | 48.27 | 50.67 | Does not comply |
| 15 | 3DCRT | 51.48 | 51.95 | Does not comply | 33.83 | 44.21 | Does not comply |
| 16 | 3DCRT | 52.91 | 51.80 | Does not comply | 41.02 | 39.53 | Does not comply |
| 17 | 3DCRT | 51.26 | 50.51 | Does not comply | 50.80 | 50.15 | Does not comply |
| 18 | 3DCRT | 49.96 | 50.07 | Does not comply | 49.62 | 47.18 | Does not comply |
| Mean/Std. Deviation | | 49.45/6.39 | 48.05/7.55 | | 45.24/6.99 | 42.54/9.97 | |

Abbreviations: $D_{max}$—maximum dose limit; $D_{mean}$—mean dose limit; OvaR—right ovary; OvaL—left ovary; Std. Deviation—standard deviation. * Patient underwent ovarian transposition.

It was not possible to perform a comparative analysis between female patients who underwent ovarian transposition and those who did not as only one patient in the sample underwent this procedure.

Female patients with gynecological tumors

All patients were treated with 50.40 Gy in 28 fractions in the supine position, including 13 patients treated with the 3DCRT technique and 27 patients with the VMAT technique, as shown in Table 6. Depending on the clinical situation, some patients underwent boost and brachytherapy; however, the doses considered were limited to the first phase to allow for a comparison across all patients. The average age of the patients was 38.73 years, with a standard deviation of 6.33. The average number of children before treatment was 1.55, with a standard deviation of 1.57.

**Table 6.** Characterization of the sample females with gynecological tumors.

| Total Patients | Average Age | Minimum Age | Maximum Age | Average Children | Dose | Position | 3DCRT | VMAT |
|---|---|---|---|---|---|---|---|---|
| 40 | 38.73 | 14 | 45 | 1.55 | 50.40 Gy | Supine | 13 | 27 |

Table 7 presents the technique as well as the maximum and mean doses delivered to the right and left ovaries of each patient. All patients who underwent ovarian transposition complied with the maximum dose limit ($V_{7.5\ Gy}$ < 26%), suggesting that the volume receiving 7.50 Gy should have been less than 26%, as well as the mean dose limit (<8.80 Gy), according to the CORSAIR project [25]. Two patients without ovarian transposition complied with these limits, while the rest did not.

**Table 7.** Technique and maximum and mean doses in Gy for the right and left ovaries of females with gynecological tumors.

| Patient | Technique | $D_{max}$ OvaR | $D_{max}$ OvaL | $V_{7.5\ Gy} < 26\%$ | $D_{mean}$ OvaR | $D_{mean}$ OvaL | $D_{mean} < 8.8$ Gy |
|---|---|---|---|---|---|---|---|
| 1 * | VMAT | 3.52 | 4.04 | Complies | 1.90 | 2.90 | Complies |
| 2 | VMAT | 46.11 | 45.51 | Does not comply | 45.12 | 43.83 | Does not comply |
| 3 * | VMAT | 3.37 | 46.98 | OvaR Complies | 2.80 | 45.16 | OvaR Complies |
| 4 | VMAT | 51.78 | 51.57 | Does not comply | 50.71 | 50.38 | Does not comply |
| 5 | VMAT | 50.81 | 52.12 | Does not comply | 49.82 | 51.44 | Does not comply |
| 6 | VMAT | 52.51 | 52.51 | Does not comply | 51.23 | 51.23 | Does not comply |
| 7 | VMAT | 2.19 | 2.19 | Complies | 1.20 | 1.20 | Complies |
| 8 | VMAT | | | Bilateral adnexectomy | | | |
| 9 | VMAT | 50.12 | 53.19 | Does not comply | 31.78 | 46.65 | Does not comply |
| 10 | VMAT | | | Unidentified ovaries | | | |
| 11 * | VMAT | 7.07 | 5.51 | Complies | 4.34 | 3.19 | Complies |
| 12 | VMAT | 51.97 | 51.86 | Does not comply | 48.87 | 48.88 | Does not comply |
| 13 | VMAT | 53.02 | 50.80 | Does not comply | 50.68 | 49.95 | Does not comply |
| 14 | VMAT | 46.06 | 46.13 | Does not comply | 45.16 | 45.19 | Does not comply |
| 15 | VMAT | 6.91 | 5.42 | Complies | 4.70 | 4.40 | Complies |
| 16 | VMAT | | | Bilateral adnexectomy | | | |
| 17 | VMAT | 13.78 | 25.84 | Does not comply | 4.40 | 16.46 | OvaR Complies |
| 18 | VMAT | 52.55 | 50.75 | Does not comply | 51.84 | 49.95 | Does not comply |
| 19 | VMAT | 51.70 | 51.22 | Does not comply | 50.94 | 49.84 | Does not comply |
| 20 * | VMAT | 6.30 | 1.60 | Complies | 1.80 | 1.10 | Complies |
| 21 | VMAT | | | Bilateral adnexectomy | | | |
| 22 | VMAT | | | Bilateral adnexectomy | | | |
| 23 | VMAT | 51.57 | 51.61 | Does not comply | 50.57 | 51.24 | Does not comply |
| 24 | VMAT | 47.05 | 47.10 | Does not comply | 45.24 | 46.38 | Does not comply |
| 25 | VMAT | | | Bilateral adnexectomy | | | |
| 26 | VMAT | | | Bilateral adnexectomy | | | |
| 27 | VMAT | 47.08 | 46.63 | Does not comply | 45.92 | 44.67 | Does not comply |
| 28 | 3DCRT | 45.47 | 46.28 | Does not comply | 44.25 | 45.83 | Does not comply |
| 29 | 3DCRT | 45.30 | 45.60 | Does not comply | 45.23 | 45.28 | Does not comply |
| 30 | 3DCRT | 46.63 | 46.84 | Does not comply | 46.34 | 46.54 | Does not comply |
| 31 | 3DCRT | 52.33 | 51.57 | Does not comply | 51.52 | 51.10 | Does not comply |
| 32 | 3DCRT | 50.60 | 50.72 | Does not comply | 50.48 | 50.11 | Does not comply |
| 33 | 3DCRT | 46.58 | 46.63 | Does not comply | 46.45 | 46.57 | Does not comply |
| 34 | 3DCRT | 46.48 | 46.52 | Does not comply | 46.23 | 46.44 | Does not comply |
| 35 | 3DCRT | | | Bilateral adnexectomy | | | |
| 36 | 3DCRT | 46.57 | 46.63 | Does not comply | 46.45 | 46.57 | Does not comply |
| 37 | 3DCRT | 46.40 | 46.40 | Does not comply | 46.27 | 46.12 | Does not comply |
| 38 | 3DCRT | | | Bilateral adnexectomy | | | |
| 39 | 3DCRT | | | Bilateral adnexectomy | | | |
| 40 | 3DCRT | | | Bilateral adnexectomy | | | |
| Mean/Std. Deviation | | 38.68/18.92 | 40.34/17.70 | | 39.63/19.67 | 38.92/18.00 | |

Abbreviations: $D_{max}$—maximum dose limit; $D_{mean}$—mean dose limit; OvaR—right ovary; OvaL—left ovary; Std. Deviation—standard deviation. * Patient underwent ovarian transposition.

No statistically significant differences were detected between the doses to the left and right ovaries ($p > 0.05$). Statistically significant differences were observed between the maximum and mean doses for both the right ($z = -4.704$; $p < 0.001$) and left ovaries ($z = -4.703$; $p < 0.001$), with the maximum dose being significantly higher in both cases.

No statistically significant differences were found between the VMAT and 3DCRT techniques regarding the maximum and mean doses delivered to both the right and left ovaries ($p > 0.05$).

There were statistically significant differences between females who underwent ovarian transposition and those who did not, regarding both the maximum and mean doses to the right and left ovaries ($p < 0.05$). Table 8 shows, on average, a reduction of 39 Gy in the maximum and mean doses to the right ovary and a reduction of 30 Gy in the maximum and mean doses to the left ovary in females who underwent ovarian transposition.

**Table 8.** Maximum and mean doses in the right and left ovaries of females who underwent ovarian transposition and those who did not, in Gy.

| Ovarian Transposition | | $D_{max}$ OvaR | $D_{max}$ OvaL | $D_{mean}$ OvaR | $D_{mean}$ OvaL |
|---|---|---|---|---|---|
| No | Mean | 44.06 | 44.47 | 42.06 | 43.05 |
| | Std. Deviation | 14.09 | 13.34 | 15.12 | 13.85 |
| Yes | Mean | 5.07 | 14.53 | 2.71 | 13.09 |
| | Std. Deviation | 1.90 | 21.69 | 1.18 | 21.40 |

Abbreviations: $D_{max}$—maximum dose limit; $D_{mean}$—mean dose limit; OvaR—right ovary; OvaL—left ovary; Std. Deviation—standard deviation.

## 4. Discussion

Our results show that the average age of the patients in the study was 38.76 years and the average number of children before treatment was only 1.25, suggesting that the parenting project may not have been complete. With the trend of postponing parenthood to older ages, it is crucial to discuss fertility plans with the patient and their family before starting therapy. This discussion should include warning them about the risk of infertility and ensuring that oncofertility is addressed within the multidisciplinary oncology team [4]. On the other hand, the evaluation of maximum and mean doses to the gonads demonstrates that pelvic radiotherapy can negatively impact patients' fertility. Therefore, it is imperative to explore ways to minimize radiation-induced toxicity. The literature includes several papers with guidelines for dose limits in organs at risk, one of the most important being the "Quantitative Analyses of Normal Tissue Effects in the Clinic (QUANTEC)" guidelines published in 2010, based on dose-volume constraints [26]. However, with the rapid evolution of radiotherapy techniques and fractionation, new specific guidelines and recommendations have emerged. The CORSAIR project has sought to consolidate all these guidelines into a single, easy-to-consult document, which was used in this work (Table 1) [25].

Despite the lack of statistically significant differences in the maximum and mean doses to the gonads between the VMAT and 3DCRT techniques in this study, most comparative studies recommend the use of the VMAT technique with daily image guidance in pelvic radiotherapy to significantly reduce the dose to organs at risk [19,27]. On one hand, with VMAT, there is an increase in the number of monitor units, potentially leading to a greater volume of tissue being exposed to low radiation doses as well as more time required for planning compared with the 3DCRT technique [28]. On the other hand, in terms of dose distribution, conformity and homogeneity indices, dose reduction to organs at risk, and treatment speed, the VMAT technique is superior to 3DCRT [29]. Clinically, it also presents advantages over 3DCRT as it allows dose escalation, better tumor control, fewer gastrointestinal and genitourinary effects, a shorter treatment time, and, consequently, greater comfort for the patient and is considered to be the gold standard for pelvic radiotherapy [30]. For these reasons, since 2020, all pelvic radiotherapy patients have been treated with the VMAT technique.

Similar to other studies evaluating the effectiveness of ovarian transposition in reducing radiotherapy doses to the ovaries [15], all women with gynecological tumors who underwent ovarian transposition met the dose limits, with a dose reduction averaging up to 39 Gy for both the maximum and mean doses to the ovaries.

As our sample of ovarian transposition patients was small, we analyzed a systematic review that included 1377 cervical cancer patients who underwent ovarian transposition [31]. From this sample, there were data on the preservation of ovarian function for 699 women who underwent ovarian transposition and radiotherapy. Ovarian function was preserved after ovarian transposition in 61.7% of patients after radiotherapy with or without chemotherapy and seemed to be even higher without combined chemoradiation [31]. This review supports our findings and concluded that ovarian transposition appears to be an effective fertility protection technique that can be offered to young patients undergoing pelvic radiotherapy [15,31].

Regarding male patients, we compared our results with a study of 67 patients that aimed to assess testicular dose in patients undergoing pelvic radiotherapy. Similar to our results, the study concluded that patients undergoing pelvic radiotherapy had the potential to receive a testicular dose of more than 1 Gy, which might result in temporary azoospermia; the maximum testicular dose can be up to 12% of the total dose [32].

Some studies suggest using shielding techniques to minimize the exposure of the gonads to scattered radiation during radiotherapy [33]. The shielding device for the testicles is a hollow sphere made of lead and Cerrobend that surrounds the testicles, which can reduce the testicular dose up to 3 to 10 times [34].

Although most studies do not consider the gonads as an organ at risk in pelvic radiotherapy, in this study, involving a real sample of 70 patients, we considered it important to include them, and suggest that they become part of atlas-based segmentation systems. We concluded that only 18.6% of patients met the maximum dose limits and 22.9% met the mean dose limits for the testicles and ovaries. This dose assessment is even more critical for ovaries where ovarian transposition has been performed, resulting in a significant dose reduction.

## 5. Conclusions

Of the 70 patients studied, 58.6% were treated with the VMAT technique, while the remaining patients received treatment with the 3DCRT technique. However, since 2020, all patients in this study were exclusively treated with the VMAT technique. Despite this, only 18.6% of patients met the maximum dose limits and 22.9% met the mean dose limits for the testicles and ovaries. No statistically significant differences were found between the right and left gonads, nor between the 3DCRT and VMAT techniques.

All patients with gynecological tumors who underwent ovarian transposition met the dose limits, with a dose reduction averaging up to 39 Gy for both the maximum and mean doses. It is important to acknowledge that only five patients in this study underwent ovarian transposition, limiting the statistical power and the generalizability of the findings. Although our results suggest that this technique is effective in reducing the ovarian dose, these data should be interpreted with caution. Further prospective research with larger cohorts is necessary to validate these preliminary observations and to assess potential complications and clinical feasibility in broader clinical settings.

This study has some limitations that must be recognized. Its retrospective design may have introduced inherent selection bias and limited the control over confounding variables. Also, the small sample size—especially the low number of patients who underwent ovarian transposition—may have restricted the statistical power and generalizability of the findings. The absence of long-term follow-up data prevented the evaluation of actual fertility outcomes, such as hormonal function preservation or successful pregnancies post-treatment. Future prospective studies with larger cohorts, standardized gonadal contouring protocols, and longitudinal fertility outcomes are essential to validate and expand upon these findings.

As future lines of research, is important to continue investing in the training of health professionals and patients in the field of oncofertility, to study how to assess the clinical efficacy of different fertility preservation techniques, and to explore new methods to reduce gonadal doses and minimize the damage caused by radiotherapy. Additionally, doses from new daily images could also be evaluated because they contribute to the cumulative doses in the gonads.

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**Informed Consent Statement:** Patient consent was waived as this was a retrospective, observational study on an anonymized basis, with no possibility of identification of nor any risk to patients.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

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