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ORIGINAL ARTICLE

Dosimetric Comparison of Inverse Planning Simulated Annealing and Manual Optimization for Intracavitary Cervix Brachytherapy

İntrakaviter Serviks Brakiterapisi için Ters Planlama Simüle Tavlama ve Manuel Optimizasyonun Dozimetrik Karşılaştırması

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ABSTRACT

Background/Aims: Different optimization methods in brachytherapy treatment planning have been used. The aim of this study is to evaluate dosimetric differences between manual optimization (MO) and inverse planning simulated annealing (IPSA) planning techniques commonly used in brachytherapy of cervical cancer.
Methods: Fifteen cervical cancer patients were included in this study. Nucletron standard tandem-ovoid (TO) applicators were used for treatment. High-risk clinical tumor volume (HR-CTV), bladder, rectum and sigmoid contouring were performed according to GEC-ESTRO recommendations. Two plans were created for each patient using IPSA and MO techniques. While a dose of 700 cGy was prescribed to the target volume during the planning phase, an effort was made to protect the organs at risk in the best way possible. IPSA and MO planning techniques were compared via dose volume histogram (DVH).
Results: There was no significant difference between HR-CTV and CI values for MO and IPSA techniques. There was a significant difference between IPSA and MO techniques for the 2cm3 volume of the rectum (p= 0.002). It was observed that the bladder was better protected by the IPSA technique. There was a 6.26% dose difference between IPSA and MO for the bladder. A significant difference was found between IPSA and MO techniques for the 2cm3 volume of the sigmoid (p= 0.002). The IPSA technique was superior to the MO technique in terms of time.
Conclusions: The IPSA technique was superior to the MO technique in terms of protecting organs at risk (OARs). IPSA provides a faster and higher quality plan in cervical brachytherapy.

Keywords: Brachytherapy, Cervix cancer, IPSA

ÖZ

Arkaplan/Hedefler: Brakiterapi tedavi planlamasında farklı optimizasyon yöntemleri kullanılmaktadır. Bu çalışmanın amacı, serviks kanserinin brakiterapisinde yaygın olarak kullanılan manuel optimizasyon (MO) ve ters planlama simüle edilmiş tavlama (IPSA) planlama teknikleri arasındaki dozimetrik farklılıkları değerlendirmektir.
Yöntemler: Bu çalışmaya on beş serviks kanseri hasta dahil edildi. Tedavide Nucletron standart tandem-ovoid (TO) aplikatörler kullanıldı. Yüksek riskli klinik tümör hacmi (HR-CTV), mesane, rektum ve sigmoid şekillendirme GEC-ESTRO tavsiyelerine göre yapıldı. IPSA ve MO teknikleri kullanılarak her hasta için iki plan oluşturuldu. Planlama aşamasında hedef hacme 700 cGy doz reçete edilirken, risk altındaki organların en iyi şekilde korunmasına çalışıldı. IPSA ve MO planlama teknikleri doz hacim histogramı (DVH) aracılığıyla karşılaştırıldı.
Bulgular: MO ve IPSA teknikleri için HR-CTV ve CI değerleri arasında anlamlı fark yoktu. Rektumun 2cm3 hacmi açısından IPSA ve MO teknikleri arasında anlamlı fark vardı (p= 0.002). IPSA tekniği ile mesanenin daha iyi korunduğu görüldü. Mesane için IPSA ve MO arasında %6,26 doz farkı vardı. Sigmoidin 2cm3 hacmi açısından IPSA ve MO teknikleri arasında anlamlı fark bulundu (p= 0.002). IPSA tekniği zaman açısından MO tekniğinden üstündü.
Sonuç: IPSA tekniği risk altındaki organların (OARs) korunması açısından MO tekniğinden üstündü. IPSA, serviks brakiterapisinde daha hızlı ve kaliteli bir plan sağlar.

Anahtar kelimeler: Brakiterapi, Serviks kanseri, IPSA

Introduction

Brachytherapy is a radiotherapy method applied by placing radioactive sources in or near the target volume. In order to ensure uniformity in dose definitions in gynecological brachytherapy, International Commission on Radiological Units and Measurements (ICRU) reports and The Groupe Europe'en Curietherapy-European Society of Therapeutic Radiation Oncology (GEC-ESTRO) recommendations are taken into consideration (1, 2). Since it is an interventional treatment, it is essential to evaluate the extent of the tumor by physical examination. The target volume is defined using physical examination and radiological imaging findings (3). Intracavitary brachytherapy is the most commonly used brachytherapy technique in cervical cancer patients (4). With the use of computed tomography (CT) in brachytherapy, three-dimensional planning has become available. In this way, target volumes, organs at risk (OARs) and applicators could be visualized directly. Three-dimensional brachytherapy planning was able to improve local control and significantly reduce complications through customized dose distributions compared to traditional two-dimensional brachytherapy planning (5). Thanks to developing computer technology, different optimization options have emerged in brachytherapy treatment planning systems (TPSs). For treatment planning in high-

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dose-rate (HDR) brachytherapy, various models have been developed to calculate dwell position and dwell time along the specified applicator path (6). Manual optimization (MO), one of the traditional treatment planning approaches, involves manually activating source locations and manually adjusting waiting times for better target coverage and preservation of OARs. This is an iterative forward planning method that requires an experienced medical physicist to spend a lot of time constantly changing the holding weights until an optimal solution is reached (7). There have been great advances in inverse planning methods as a result of mathematical optimization algorithms widely used in external beam radiotherapy (EBRT). The principle of the inverse planning optimization algorithm is to seek the minimum value of an aggregate objective function based on a set of predefined dose targets (8). Compared with forward planning, inverse planning has advantages such as less planning time, better repeatability, higher target coverage, and lower dose to OARs. As a result of advances in optimization, inverse planning simulated annealing (IPSA), which is based on a mathematical algorithm in which clinical targets are defined as mathematical equations, has begun to be used (9, 10). This method takes into account the anatomy of the area. Dose limitations, minimum and maximum dose criteria for the target volume, and dose criteria in the desired volumes are determined for OARs. Dose distributions obtained with inverse optimization give dose distributions similar to the target coverage obtained with graphical optimization (11). Especially in inhomogeneous structures, IPSA provides lower-risk organ dose and higher dose homogeneity compared to the geometric optimization method. There is no need for manual adjustments for IPSA (12,13).

Compared to the MO technique, which takes a long time to plan, treatment planning with IPSA takes a very short time. This study aims to dosimetrically investigate IPSA and MO techniques for cervical cancer brachytherapy.

Material and Methods

Patients and treatment

In this study, 15 cervical cancer patients who received brachytherapy treatment in our clinic between February and October 2023 were retrospectively re-evaluated. Ethical approval was obtained for the study from the local ethics committee of our institution (Ethics Committee Permission No: 2023/412). FIGO staging of all patients is presented in Table 1. All patients received 45 to 50.4 Gy full pelvic EBRT followed by 4 fractions of high dose rate (HDR) brachytherapy with a prescription dose of 7 Gy. Geneva tandem-ovoid (TO) applicators compatible with CT and magnetic resonance (MR) were used in this study. High-risk clinical tumor volume (HR-CTV), bladder, rectum and sigmoid contouring were performed according to GEC-ESTRO recommendations. Two different treatment plans were created for all patients. Initial plans were optimized with clinically used IPSA for patient treatment. Second plans were created retrospectively with MO. All treatment plans were planned using Oncentra Brachytherapy TPS v4.6 (Elekta AB, Stockholm, Sweden) with Flexitron afterloader unit 192Ir source.

Table 1. FIGO staging and treatment distribution of patients.

Patient	Age	Treatment	FIGO Stage	BRT (cGy)
1	57	EBRT+BRT	IIB	4X700
2	41	EBRT+BRT	IIIA	4X700
3	55	EBRT+BRT	IIB	4X700
4	60	EBRT+BRT	IIB	4X700
5	57	EBRT+BRT	IIB	4X700
6	54	EBRT+BRT	IIB	4X700
7	75	EBRT+BRT	IIB	4X700
8	75	EBRT+BRT	IIIC	4X700
9	52	EBRT+BRT	IIIA	4X700
10	55	EBRT+BRT	IIB	4X700
11	55	EBRT+BRT	IIIB	4X700
12	53	EBRT+BRT	IIB	4X700
13	72	EBRT+BRT	IIB	4X700
14	58	EBRT+BRT	IIIC	4X700
15	60	EBRT+BRT	IIB	4X700

Manual treatment planning

After CT images were obtained for planning purposes, the images were transferred to TPS via DICOM. Target volume and OARs were defined by the radiation oncologist. Depending on the tandem and ovoids, the initial and final stopping positions of the weld and the stopping distance between the sources were determined manually. According to the Manchester dosimetry system, A points were determined 2 cm above the upper surface of the ovoids, 2 cm away from the tandem, to the right and left (14). Dose points were created around the applicator to reflect the shape of the target volume. Both source stop positions and stop times were manually adjusted to ensure a homogeneous dose throughout the implant, to deliver the desired dose to the target volumes, and to deliver the lowest dose within the OARs determined criteria. These adjustments were repeated until the desired dose distribution was achieved. At the end of each manual adjustment, the computer dose distribution was recalculated. All manual optimization plans were performed by a single medical physicist.

Inverse planning: IPSA

In inverse optimization, new plans were created by copying the manually optimized plans without making any changes to their contours. IPSA provides a combination of source activation, dose normalization, dose optimization, and dose prescription. Optimization can thus be carried out immediately after contouring and applicator reconstruction. An attempt was made to ensure that 90% of the HR-CTV received 100% of the defined dose. Dose limitations were made to ensure that the 2cm³ volume of the rectum, sigmoid and bladder received the least dose possible. The dose limitations used for IPSA are shown in Table 2. Before optimization, HR-CTV was defined as the reference target volume. Weight and dose constraints for each plan were changed until an optimal plan that met the dose target parameters of both target volume and OARs was achieved.

Table 2. Dose optimization parameters used for IPSA plans

Contour	Min (cGy)	Weight	Max (cGy)	Weight
HR-CTV (D90)	700	85		
Rectum (D_{2cm3})			400	45
Sigmoid (D_{2cm3})			400	40
Bladder(D_{2cm3})			450	40

Evaluation

For 15 patients using the tandem-ovoid applicator, the dose volume histogram (DVH) was used to evaluate the dosimetric difference between the IPSA and MO plans. All plans were normalized to cover 90% of HR-CTV with 100% of the prescription dose. In dosimetric evaluation according to HR-CTV, the minimum dose D90 given to 90% of the target volume was evaluated. For OARs, the D2cm3 dose, which is the most exposed 2cm3 volume, was evaluated. Conformity index (CI) was used to compare two optimization techniques. CI was calculated according to the formula below (15).

Statistical Analysis

All data were recorded and analyzed in Statistical Package for Social Sciences (SPSS) software (version 25.1, IBM). The mean and standard deviation were calculated for two different treatment plans, and the Paired Samples t-test was used to evaluate the relationship between them. P <0.05 was considered statistically significant.

Result

In the study, MO and IPSA plans were evaluated for both targets and OARs for 15 patients. The dose distribution for HR-CTV of the plans made with MO and IPSA is shown in Figure 1.

D90, CI values for the target volume and D2cm3values for OARs are shown in Table 3. The average age of the patients included in the study was 58.6 years. There was no significant difference between HR-CTV and CI values for MO and IPSA techniques. CI values were found as 0.992 and 0.996 for IPSA and MO techniques, respectively. There was a significant difference between IPSA and MO techniques for the 2cm3 volume of the rectum (p= 0.002). It was observed that the bladder was better protected by the IPSA technique. There was a 6.26% dose difference between IPSA and MO for the bladder. A significant difference was found between IPSA and MO techniques for the 2cm3 volume of the sigmoid (p= 0.002). In brachytherapy, active irradiation time is very important for treatment quality. It was observed that the active irradiation time was 7.88% less in the plans made with the IPSA technique.

Table 3. Comparison of dosimetric parameters between IPSA and MO plans.

Parameters	IPSA (Mean±SD)	MO (Mean±*SD*)	ΔMean±*SD* (IPSA-MO)	p
HR-CTV D_{90} (cGy)	700.40±0.32	700.31±0.27	0,09±0.47	0.476
CI	0.992±*0*.01	0.996±*0*.01	0.01±*0*.01	0.246
Rectum $D_{2cm}{}^3$ (cGy)	440.30±101.96	461.54±93.27	21.23±21.17	0.002
Bladder $D_{2cm}{}^3$ (cGy)	521.55±58.56	554.23±56.16	32.67±61.72	0.060
Sigmoid $D_{2cm}{}^3$ (cGy)	355.46±63.18	399.44±79.78	43.97±43.78	0.002
Irradiation time (s)	1043.93±145.99	1126.26±*136.76*	82.33±79.73	0.001

IPSA: inverse planning simulated annealing, MO: Manual optimization, CI: Conformity index, HR-CTV: High-risk clinical tumor volume

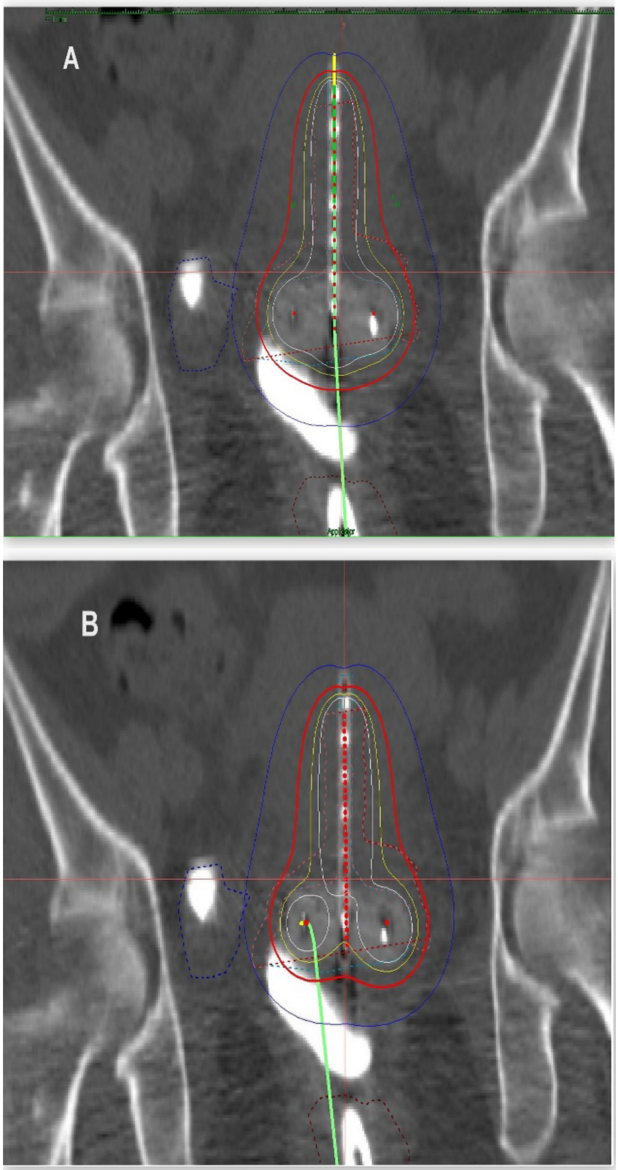

Figure 1. 90% dose distribution for HR-CTV (A: MO, B:IPSA)

Discussion

Brachytherapy has been one of the most important components of cervical cancer treatment for many years. One of the biggest advantages of brachytherapy is that it gives the required dose to the target volume while giving the minimum dose to nearby OARs. Different optimization techniques are used to obtain the ideal dose distribution. The most commonly used optimization techniques in cervical brachytherapy are IPSA and MO. IPSA plays an important role in obtaining the ideal plan in a short time, especially in complex anatomical structures. Many positive results have been published after treatment with IPSA (16). Tinkle et al. concluded that patients treated using the IPSA optimization technique for cervical brachytherapy had minimal toxicity and excellent local control (17).

Trnková et al. compared manual and inverse optimization techniques using a tandem-ring applicator in cervical brachytherapy. In their study, they could not see a significant difference between MO and IPSA for D90 of HR-CTV. However, they found that IPSA was better than the MO technique for the 2cm3 volume of the rectum. Our current research contains results parallel to Trnková et al. There was no significant difference between the two techniques for HR-CTV, but better protection was provided in the plans made with IPSA for the 2cm3 volume of the rectum (18).

Fu et al. examined two inverse optimization techniques for cervical cancer and reported that the IPSA technique reduced the treatment time. In our current study, the active irradiation time for IPSA was 7.88% shorter compared to the plans made with the MO technique (19). Roy et al. reported that in plans made with IPSA for interstitial brachytherapy of cervical cancer, the rectum and bladder received lower doses compared to the MO technique. In our intracavitary cervix brachytherapy study, it was found that both the rectum and bladder were better protected in plans made with IPSA (20).

Wang et al. (15) investigated the advantages of different optimization techniques for cervical cancer. In their study, they tried to achieve equal dose distribution for the target volume in all techniques. They found that IPSA was superior to graphic optimization for the 2cm3 volume of Sigmoid. In our current study, a significant difference was found between IPSA and MO techniques for sigmoid (p = 0.002). The IPSA technique better preserved the sigmoid critical organ (21).

Tang et al. aimed to compare the dosimetric difference between graphical optimization and IPSA plans in cervical cancer brachytherapy. In their study, they emphasized the superiority of IPSA in rectum and bladder doses while giving a dose of 600 cGy to the target volume. Additionally, they noted the advantage of IPSA in irradiation time. In our current study, while a dose of 700 cGy was prescribed to the target volume, the superiority of the IPSA technique was found in the rectum and bladder doses. In addition, the IPSA technique was found to be superior in terms of active irradiation and treatment planning time (22).

Conclusion

Optimized plans with IPSA and MO techniques in intracavitary brachytherapy of cervical cancer may not create a significant difference in target dose; however, IPSA ensures that OARs receive the least dose. With IPSA, treatment planning time and active irradiation time are reduced, thus increasing the patient's treatment quality.

Author Contributions

Conception: O.V.G., Data Collection and Processing: O.V.G., G.İ., Design: O.V.G., H.B., Supervision: O.V.G., M.D., Analysis and Interpretation: O.V.G., Literature Review: O.V.G., Writer: O.V.G., Critical Review: O.V.G., M.D.

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