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The Effect of Source Step Size in Uterine Cervix Intracavitary with High Dose Rate (HDR) Brachytherapy: A dosimetric Comparative Study

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ABSTRACT

The presented study discusses the impact of source step size on dose distribution in patients undergoing high-dose-rate after-loading Brachytherapy with cobalt-60 (Co-60) for cervical cancer (Ca-cx). *Flexitron*® Cobalt-60 HDR Brachytherapy unit with Co-60 source, which has an active core 0.5 mm diameter and 3.5 mm active core length was used. *Oncertra*® *Brachy* v4.6, (Elekta, Stockholm, Sweden) treatment planning system was also used in patient dose distribution and calculation. The respective study is based on the database of 11 patients Ca-cx already treated with Co-60 intracavitary Brachytherapy with 21 Gy treatment doses for each patient delivered in three fractions after a 45 Gy of external beam radiotherapy. The assessment of the entire treatment process included an examination of the prescribed dose volume, organ-at-risk doses, and treatment time. This analysis was performed for varying source step sizes 1 mm, 3 mm, 5 mm, and 7 mm considering each patient individually. our general results we can conclude that 5 mm step size is the best choice to do brachytherapy plan to achieve organ at risk constrains, treatment time and prescribed dose coverage volume were affected by the increase of source step size.

INTRODUCTION

The practice of brachytherapy began shortly after Madam Curie's discovery of radium (Ra-226)[1] in the late 19th century. By the early 20th century, researchers had recognized the effectiveness of radiation therapy in treating various malignant diseases [2], [3]. Brachytherapy, also known as internal radiotherapy or curie therapy, is a type of radiotherapy where a radioactive source is placed close to or inside the treatment area. It can be used alone or in combination with other treatments such as surgery, chemotherapy, and external beam radiotherapy (EBRT)[4]. These procedures of treatments can be used to treat some types of tumors that necessitate high doses of radiation such as prostate cancer, adenocarcinoma, and cervical carcinoma[5]. Cervical carcinoma (Ca-cx) stands as the second most common cancer among women in regions with low to medium levels of human development. The treatment options for this condition include EBRT and intracavitary brachytherapy [3]. In the brachytherapy, achieving accurate and careful treatment planning is crucial to ensuring the delivery of the prescribed dose to the target while minimizing radiation toxicity to surrounding organs at risk (OARs)[6]. The goal of brachytherapy treatment planning is to achieve an optimal treatment plan that balances the delivery of the necessary therapeutic dose to treat the tumor while minimizing the impact of ionizing radiation on the healthy tissues surrounding it. The dose calculation in the brachytherapy treatment planning system is dependent on the type of radioactive source used in the treatment time [7].

Over the past few decades, there have been several comparative studies examining the use of Co-60 and Ir-192 sources in high dose rate (HDR) brachytherapy[2].

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One advantage of Co-60 is that it only requires 33% of the activity of Ir-192 to deliver an equivalent dose rate, making it more applicable [8] while in the treatment planning system, there isn't typically a significant difference between Ir-192 and Co-60 in isodose distributions to the target volume [9],[10] . Despite various dosimetric studies on Co-60 and Ir-192 sources, there remains a gap in the dosimetric study of the cervix based on step size variation[11]. On the other hand, the source step size movement parameter plays an important role in treatment planning. It is the primary item in enhancing the treatment dose distribution. In HDR brachytherapy, achieving an optimal implant dose distribution relies on several key parameters, including source dwell times and dwell positions[12]. The quality of a treatment plan produced for an HDR unit equipped with Co-60 depends on the positions of the source dwell, while the accuracy of dose delivery to the tumor site depends on achieving the desired dose gradient through precise source positioning. In brachytherapy treatment planning, the treatment time (TT) is influenced by the prescribed dose and the half-life of the radiation source [13]. However, it's important to note that the treatment time (TT) plays a significant role in determining the dose distribution and ultimately the success of radiation therapy, whereas the absorbed dose is proportional to the TT[14]. Adjusting the source step size presents an efficient method to modify the source dwell positions, and in turn, treatment time can be varied. This approach provides greater flexibility in the number of dwell positions, leading to a more effective treatment plan. Therefore, it's critical to carefully consider all of these factors when planning radiation therapy.

In this study, we will focus on the impact of choosing a step-size factor in the brachytherapy treatment plans for cervix cancer. Through this investigation, we seek to evaluate the efficacy of different step sizes ranging from 1 mm to 7 mm in achieving the desired therapeutic outcome and to identify the most effective approach for maximizing treatment results for intracavitary brachytherapy implants using a remotely after-loading HDR unit consisting of Co-60 source [12]. We believe that this study will contribute to the ongoing dialogue on effective treatment planning in brachytherapy.

MATERIALS AND METHODS

The current retrospective study included twenty-one patients with cervical carcinoma (Ca-cx) with Co-60 HDR intracavitary brachytherapy. All patients received a treatment regimen consisting of 45 Gy delivered in 25 fractions of external beam radiotherapy, followed by HDR brachytherapy with a dose of 21 Gy delivered in three fractions. According to our patients' data, the average number of cases of cervical carcinoma (Ca-cx) treated annually ranges from 10 to 12 cases. However, in this study, we relied on the list of cases that were treated during the past two years with a total of 21 cases; therefore, we investigated this study based on this statistic. This work was approved by the Ethics Committee of South Valley University, Faculty of Science (Permit Number: 006/06/24). In all cases, brachytherapy treatment is administered following the course of external beam radiation treatment. using the applicator tandem and Ring for all patients (Fig. 1).

Under general anesthesia and after obtaining pre-anesthetic clearance, the brachytherapy applicator was then inserted with the patient in the lithotomic position and placed in the dorsal lithotomy position in stirrups. Additionally, a *Foley's* catheter was introduced into the urinary bladder, and its balloon was inflated with 7 cc of diluted *urografin* dye. The *Elekta Flexitron*® Cobalt-60 HDR brachytherapy Unit was used in this study. It has a Co-60 source with an active core diameter of 0.5 mm and an active core length of 3.5 mm. The MRI images were exported to the treatment planning system via networking. For treatment planning, we used *Oncertra*® Brachy v 4.6 (Elekta, Stockholm, Sweden), which allows selecting a source step size from 1 to 7 mm. A physician delineated the targeting volume and surrounding organs at risk (OAR), with Intermediate-Risk-CTV (IR-CTV) and High-Risk-CTV (HR-CTV) contoured for each patient as the target volumes. The bladder, rectum, and sigmoid were contoured on treatment plans as OAR (fig.2).

We computed volumetric parameters, specifically $D_{0.1}$ cc (dose to 0.1 cubic centimeter volume) and D_2 cc (dose to 2 cubic centimeter volume), for both the bladder, rectum, and sigmoid following gynecological guidelines. In our treatment policy, we follow the recommendations of the Groupe *Européen de Curiethérapie* and the European Society for Radiotherapy & Oncology (GYN GEC-ESTRO) [15],[16] these recommendations suggest recording and documenting the calculated doses to a specific point called the "A" point. Both right and left doses of Point A were recorded for all cases. The position of this point was determined based on the protocol of the "*Manchester System*"[17], where a dose of 7 Gy was prescribed to point A [18]. For each patient, we performed a retrospective treatment planning process employing source step sizes ranging from 1 mm to 7 mm.

Dose calculations were performed following the guidelines outlined in the American Association of Physicists in Medicine (AAPM) Task Group No. 43 Report (TG-43) [19]. We compared TT and the volume covered by the prescribed dose.

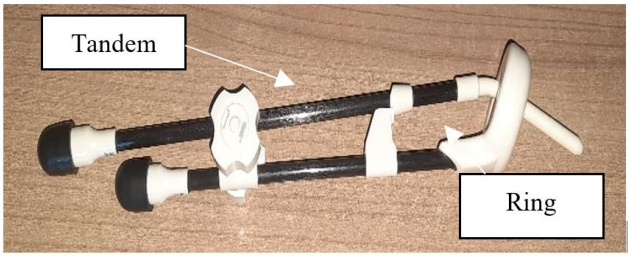

Fig. (1): The compact of Tandem and Ring Applicators.

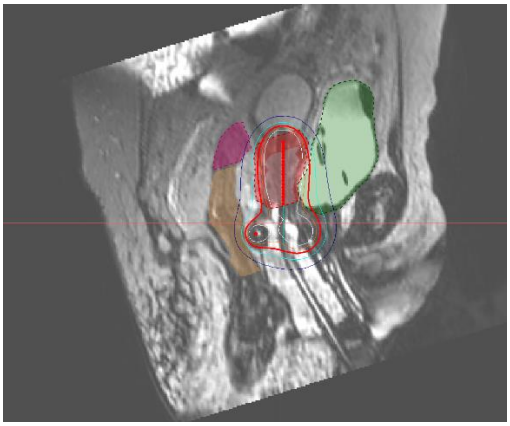

Fig. (2): Typical intracavitary Brachytherapy plan is illustrated in sagittal perspectives MRI, with delineated target & OAR structures and applicators inserted.

STATISTICAL ANALYSIS OF THE DATA

The data was entered and analyzed using IBM SPSS software version 20.0 provided by IBM Corp. An F-test (ANOVA) was used to compare more than two groups for normally distributed quantitative variables. The Shapiro-Wilk test was employed to assess the normality of the distribution. Descriptive statistics such as range (minimum and maximum), mean, and standard deviation were used to analyze the quantitative data. Results were considered significant at the 5% level.

RESULTS

Figures a, b and, c shows the variation of dose to OARs, volume covered by the prescribed dose, and treatment time (TT) according to the variation in step sizes for the twenty-one patients with cervical carcinoma (Ca-cx) after planning with Co-60 HDR intracavitary brachytherapy. Figures (3-a, b and c) indicate the results of the investigated parameters using smaller step sizes (1 and 3 mm) individually. As shown, the mean values of $D_{0.1}$cc for the investigated cases using a 1 mm step size were 9.77±1.96, 8.97±1.91, and 5.05±1.89 Gy for $D_{0.1}$cc of the bladder, rectum, and sigmoid, respectively. For the D_2cc of bladder, rectum, and sigmoid, the mean dose values were 7.44±1.18, 6.03±1.49, and 3.53±1.13 Gy. Also, the mean TT value using this step size was 22.77 ± 3.57 min. Figures shows the results of the same parameters, but with a 3 mm step size.

As shown in this figures, there is no significant difference between its recorded results, which was based on step size lower than step size at 3 mm, where 9.84±1.41, 8.49±1.9, and 5.09± 1.93 Gy were the mean dose values of $D_{0.1}$cc of bladder, rectum, and sigmoid, respectively, while the mean dose values of $D_{0.2}$cc of bladder, rectum, and sigmoid were 7.52±0.84, 5.94±1.5, and 3.47±1.2 also, respectively. In addition, the mean TT value was 22.84 ± 3.33 min.

The results of using longer step sizes (5 and 7 mm) are indicated in figures (3-a, b and c) respectively. As presented in figures, the results indicated that the mean values of $D_{0.1}$cc were 9.71±1.6, 9.3±2.35, and 5.43±2.05 Gy for Bladder, Rectum, and Sigmoid, respectively; and 7.41±1.02, 6.18±1.54, and 3.51±1.13 Gy for $D_{0.2}$cc of bladder, rectum, and sigmoid, respectively. The mean TT was 23.21±3.57 min.

There are some significant differences between the results of step size 3, 5 and 7 mm indicated the results of using 7 mm step sizes for the investigating cases. The D0.1cc for bladder, rectum, and sigmoid were 9.72±1.73, 9.32±2.22, and 5.63±2.25 respectively; and 7.60±1.28, 6.19±1.53, and 3.70±1.26 Gy for $D_{0.2}$cc of bladder, rectum, and sigmoid respectively. A 23.30±3.5 min was the mean value of TT using a 7 mm step size as shown in figure(3-a).

The optimal step size for a 0.1cc bladder is 5 and 7 mm, while for a 2cc bladder, it is 5 mm. For the 0.1cc and 2cc rectum, the best step size is 3 mm. Additionally, a 0.1cc sigmoid benefits from a 1 mm step size, whereas a 2cc sigmoid benefits from a 3 mm step size.

Figures 3-a, b, and c summarize the mentioned results but according to the type of QAR. As shown in these figures, lower mean dose effect on 0.1 & 2 cc of bladder When treated with 5 mm step size but higher dose effect on 0.1& 2 cc of rectum and sigmoid when it treated with the same step size and vice versa for step sizes lower than 5 mm. Figures 4-a&b showed the variation of prescribed dose volume and TT with step size. prescribed dose volume and TT increases with an increase in step size.

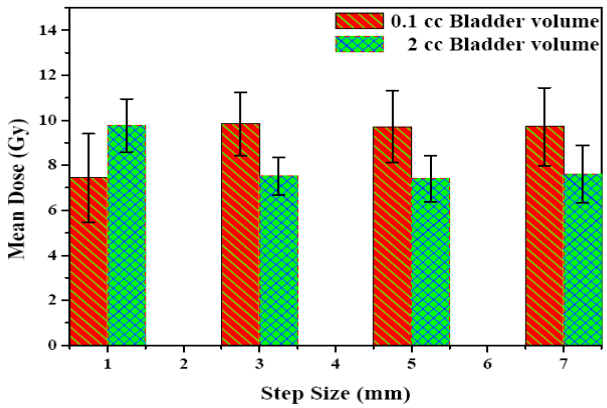

Fig. (3-a): The variation of the bladder at different step size.

F = 0.28,0.122 at 0.1cc,2cc bladder volume, P>0.05, F: F for One-way ANOVA test, p: p value for comparing between the studied groups, where a: Significant with 1mm, b: Significant with 3 mm , c: Significant with 5mm.

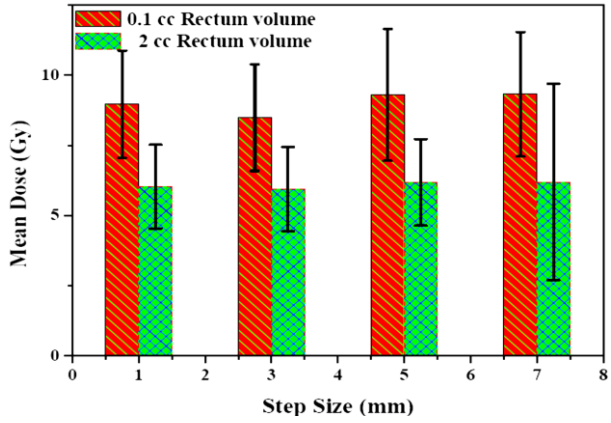

Fig. (3-b): The variation of the rectum at different step size.

F =0.696, 0.125 at 0.1cc,2cc rectum volume, P > 0.05, F: F for One-way ANOVA test, p: p value for comparing between the studied groups, where a: Significant with 1mm, b: Significant with 3 mm, c: Significant with 5mm.

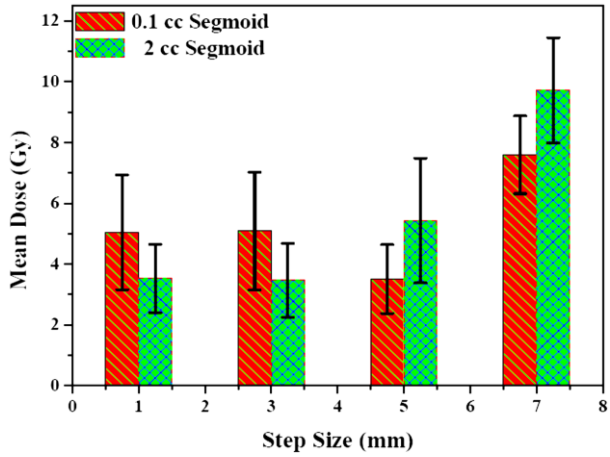

Fig (3-c): The variation of the sigmoid at different step size.

F =0.380, 0.134, At 0.1cc,2cc sigmoid volume, P > 0.05, **F**: **F for One-way ANOVA test,** p: p value for comparing between the studied groups, where a: Significant with 1mm, b: Significant with 3mm, c: Significant with 5mm

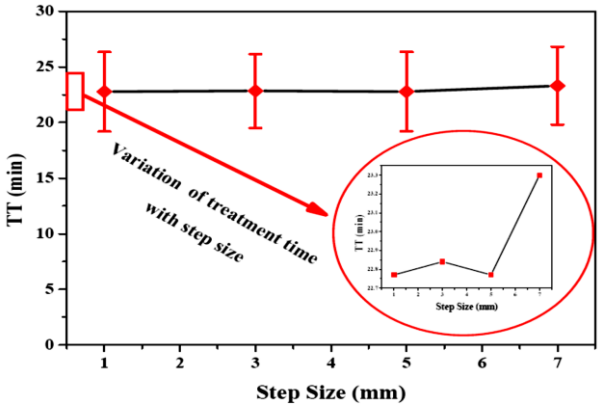

Fig. (4-a): The variation of the TT at different step size.

F=0.118, P>0.05, F: F for One-way ANOVA test, p: p value for comparing between the studied groups, where a: Significant with 1mm, b: Significant with 3mm c: Significant with 5mm.

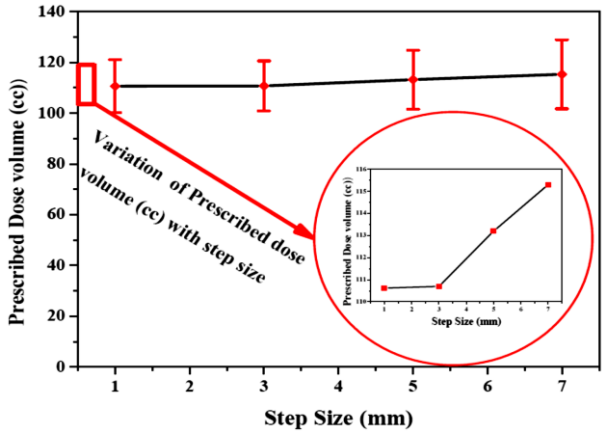

Fig. (4-b): The variation of the prescribed dose volume at different step size.

F=0.799, P<0.05, F: F for One-way ANOVA test, p: p value for comparing between the studied groups, where a: Significant with 1mm, b: Significant with 3mm, c: Significant with 5mm

DISCUSSION

According to the study protocol, all 21 plans were analyzed to determine the optimal step size that would provide the best target coverage with acceptable quality indices and lower doses to organs at risk (OARs). The mean prescribed dose coverage volume (fig. 4-b) increases with larger step sizes. Both 5 mm and 7 mm step sizes achieve good target coverage. If only target coverage is considered, 7 mm is preferable due to its higher coverage. However, our results indicate that when considering both target coverage and constraints on normal structures for a clinically acceptable plan, a 5 mm step size is more favorable in (fig. 4-a), it is evident that TT increases as the step size increases. Our study

indicates that plans with step sizes different from 5 mm demonstrate at least a 6-second reduction compared to the 7 mm step size. Our study indicates that plans with step sizes different from 3 mm demonstrate at least a 23-second reduction compared to the 5 mm step size. The total dwell time during treatment planning was determined by multiplying the dwell time per position by the number of active positions. As the position step size increased, the number of active positions decreased for each treatment length. This led to an increase in the dwell time per position to achieve the prescribed dose.

Therefore, increasing the position step size leads to a higher total dwell time. However, the total treatment time is primarily influenced by the radiation delivery time, not the total dwell time. Moreover, larger position step sizes result in increased travel time between neighboring dwell positions due to the greater distances traveled. We observed the minimum rectum and sigmoid colon doses with a 3 mm step size. A minimum bladder dose was observed for a 5 mm step size. When dwell positions are densely placed, the bladder, which has a smaller volume, receives a higher dose compared to the rectum and sigmoid colon, which occupy most of the treatment volume. then the dose to the bladder is greater, the doses to the rectum and sigmoid colon are less. $D_{0.1}$cc represents the hottest point in bladder volume, whereas D_2cc is considered a hot spot for the bladder. D_2cc represents dose to bladder volume.

The data shows a gradual increase in bladder and rectum doses with larger step sizes. This can be attributed to the variation in dose distribution near the radiation source, where higher photon attenuation occurs in high-dose rate brachytherapy. The source dwell positions and times are vital parameters. Given that most patients are sedated or under anesthesia during treatment, the overall treatment duration holds significant importance.

Closer work was presented by *Park et al*. When they investigated the effect of different step sizes on the dose distribution. Park et al. in their work found that the step sizes yielding the most homogeneous dose distributions are optimal at 4-6 mm[20]. Moreover, they find that finer step sizes (1-3 mm) do not improve dose homogeneity. Whereas coarser step sizes (7-10 mm) provide lower dose homogeneity. The findings of our study are more or less in good agreement with the published studies. on the initial input parameters like step size and maximum dwell time. Their study on prostate implants identified the step size of 5 mm and the maximum dwell time of 40 s as the optimum values[11]. Increasing the source step size in the treatment plan increases the magnitude of dosage to hot areas, as demonstrated by the study by Odgers et al.[21] . Bhadur et al. [22] reported similar results with Ir-192 HDR.

CONCLUSION

Our clinical study on Ca-cx Brachytherapy implants determined that a step size of 5 mm or less is optimal. Lower step sizes resulted in reduced rectal and sigmoid doses, while the bladder dose was found to be optimal at a 5 mm step size. So, as step size increased organs at risk increased. The TT increased with increased step size non significantly, it is not significant in-patient discomfort during treatment sessions. The dose distribution was more homogeneous for all position steps; however, it was not significant. Particularly, differences of less than 10% could be ignored in the HDR treatment due to the high dose gradient. So, we may conclude that better dose distribution and dose homogeneity occur for the source step size of 5 mm.

AUTHORS' CONTRIBUTIONS

The research point was supervised by S. Harb along with the team Mahmoud H. Abdelgawad, Alaa H. Said and Amna Abedelrahim. Practical part has been completed by Amna Abedelrahim, and the research results were analyzed and reviewed by the team.

AVAILABILITY OF DATA AND MATERIALS

All the data used to support the findings of this study are included in the article. Other data are available from the corresponding author upon request.

COMPETING INTERESTS

The authors declare that they have no competing interest

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