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Carcinoma of the uterine cervix: a 3D – CT analysis of dose to the internal, external and common iliac nodes in tandem and ovoid applications

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Abstract

Purpose: To describe external, internal and common iliac dose rates estimated with 3D-computed tomography (CT) based dose calculations in tandem and ovoid brachytherapy.

Materials and methods: Thirty patients with carcinoma of the uterine cervix received low dose rate brachytherapy with a CT-compatible Fletcher–Suit–Deldos device. A total of 36 implants were performed with axial CT images used to identify internal iliac, external iliac, and common iliac vessels. Dose rates on the surfaces of these vessels were calculated for the purpose of estimating the dose to their associated lymph nodes.

Results: In 22 out of 72 comparisons, point B overestimated the maximum dose with the external iliac nodes. In 21 out of 72 comparisons, point B overestimated the maximum dose with the internal iliac nodes. In all cases, Point B overestimated the minimum dose to the internal and external iliac nodal chains.

Conclusion: It was found that Point B dose is similar to the maximum common iliac nodal dose. Patient to patient variability, of Point B dose, warrants further study of dose distributions to the nodal chains. The minimum dose to the external iliac nodal chain at the bifurcation of the nodal chains may provide a useful measure of 'pelvic side wall dose' and deserves further study to see if it can be correlated with pelvic side wall control and complications.

Keywords: Brachytherapy; Cervical cancer; CT dosimetry; Iliac nodes

1. Introduction

Cervical cancer can spread to the obturator lymph nodes (the medial group of the external iliac lymph node chain), the hypogastric lymph nodes (part of the internal iliac lymph node chain), and the common iliac lymph nodes. The most common involved lymph node groups are the obturator and external iliac lymph nodes (67%) followed by the common iliac lymph nodes (14%) and the hypogastric lymph nodes (7%) [5]. The overall incidence of lymph node involvement varies according to stage. Stage I patients have a 13–16% risk, stage II a 27–45% risk, and stage III a 47–66% risk. [6]. It has long been recognized that an adequate dosage of radiation needs to be administered to these lymph nodes in order to sterilize the disease [7].

The treatment of these lymph nodes is typically a combination of external beam radiation therapy and brachytherapy with tandem and ovoids. Although the dose from the external beam treatment can be reliably calculated the dose administered with the brachytherapy component of the treatment is more difficult to calculate. This is secondary to the fact that the lymph nodes are not visible on orthogonal radiographs without lymphangiography and that the standard commercially available applicators are not computed tomography (CT) compatible, precluding more accurate estimates of dose using 3D techniques. Recognizing the need to estimate doses to the pelvic nodes, Tod and Meredith [7,8] defined Points A and B, relative to the applicator, as important points at which to document the dose for each patient's application. By so doing they were attempting to provide a 3D description of the dose relative to the applicator. For example, Point B dose relative to Point A dose characterized the dose gradient implicit in the variable ability (patient to patient) to spread the ovoid sources laterally towards the pelvic sidewall. Point B was used as the reference dose to represent the lateral parametria, 'pelvic side wall', or 'pelvic lymph nodes'from the brachytherapy portion of the patients' treatments. Previous studies [1] have shown a correlation of dose to the parametria and local control. In some institutions, it is common clinical practice to decide on further external beam treatments directed to the pelvic lymph nodes based upon the Point B calcu-

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lation. At other institutions, a dose calculation at a position located at the widest part of the bony pelvis is used. However, direct calculation of dose to anatomically identified lymph nodes has not been reported previously.

At Duke University, in an effort to improve our understanding of the use of brachytherapy for this disease, we have instituted CT based studies of 3D dose distributions delivered during these implants [4,9]. Following placement of a CT compatible tandem and ovoids device [9], axial CT images were obtained with the device in place. As a part of this study, we have determined the dosage to the internal, external, and common iliac lymph node chains based on the CT data. Our results and a comparison with the commonly used Point B dose rates are presented in this paper.

2. Materials and methods

From August 1992 to October 1997, 36 tandem and ovoid applications with a CT compatible Fletcher–Suit–Deldos device [9] were performed at Duke University in 30 patients. Six patients had two implants. Cs-137 sources were used. The dose to Point A was administered to all patients in the study via whole pelvic external beam radiation therapy (40–50 Gy using a 4-field box technique) plus (30–40 Gy) brachytherapy implant boost. The total dose to Point A was in the range 75–85 Gy. A total dose of 50–65 Gy was desired at Point B. The patients' stage at presentation and/or the presence of pelvic lymphadenopathy determined whether higher dosages were administered. If the physician deemed necessary, pelvic sidewall boosts were administered to raise the nodal (Point B) dose.

The CT compatible applicator is made out of an aluminum alloy and has similar physical dimensions as the standard Fletcher–Suit–Deldos device. Visualization of the applicator and anatomy without appreciable artifact makes the 3D dosimetric analysis possible [9]. Each patient was scanned from 2 cm above the tandem to 2 cm below the inferior aspect of the ovoids in 3-mm slices. Outside this region images were 10 mm apart. The axial CT images were used to define the spatial relationships between the tandem, ovoids, and pelvic anatomy including the internal, external and common iliac vasculature. The iliac vessels were easily seen on axial CT images. The iliac lymph nodes 'hug' these vessels [2]. Since the lymph nodes are not easily distinguished from their juxtaposed vessel on non-contrast CT images, the vessels were contoured as a surrogate in addition to any visible lymph nodes. The doses were calculated over a surface distribution of points with 1-mm spacing. These points were determined by interpolation over the CT outlined structure points.

The CT scan data was analyzed to determine the center and orientation of each radioactive source. Dose matrices were calculated around each source [11]. The dose was superimposed on the 3D anatomic reconstruction [10]. The method of calculation of dose to Point A from CT scans was defined previously [4]. In this work, the dose to Point B was calculated from the plain orthogonal films in the manner done in our department for a number of years. Namely, at a level 2 cm above the flange on the tandem, we define BR (BL) to lie 5 cm to the right (left) of the patient's midline. If the application is exactly midline with equal separation between ovoids, dose to BR and BL would be identical, but this is rare in practice.

A comparison of dose rates with the iliac vascular/lymph node chains vs. Point B is presented. These dose rates are presented as a percentage of the Point A dose rate. This makes the results dependent less upon loading differences and more correctly represents the variations arising from the patient anatomical differences. Maximum and minimum dose rates to the internal and external iliac lymph node chains were obtained. No effort was made to determine minimum dose rates to the common iliac nodes because it is well known that the minimum dose rate is negligible, therefore, only the maximum dose rates to the common iliac nodes were obtained. The minimum dose rate to the external iliac chain occurred anterior and inferior, where the external iliac vessels become the femoral vessels. This region was felt to be clinically insignificant given the fact that cervical cancer does not typically metastasize to the inguinal/femoral lymph nodes. A secondary dose rate for the external iliac lymph node chain was defined at the bifurcation of the external and the common iliac lymph node chains. This dose rate (EIBmin) was chosen as the minimum dose rate to the external iliac lymph node at the bifurcation. The dose rate ratios are defined as follows:

- IImax – internal iliac lymph node maximum dose rate/Point A dose rate;
- IIImin – internal iliac lymph node minimum dose rate/Point A dose rate;
- EImax – external iliac lymph node maximum dose rate/Point A dose rate;
- EImin – external iliac lymph node minimum dose rate/Point A dose rate;
- EIBmin – external iliac lymph node bifurcation dose rate/Point A dose rate;
- CImax – common iliac lymph node maximum dose rate/Point A dose rate.

3. Results

The top part of Fig. 1 shows a representative CT image at a level in the common iliac region. The left and right common iliac vessels are outlined in the image. Fig. 1 also shows a CT image lower in the pelvis, after the bifurcation of the common iliac into the internal and external iliac vessels. Those vessels are outlined, as shown. This outlining procedure was done on all images throughout the implant region. The final result is a 3D representation of the pelvic anatomy, iliac vessels, applicator and organs of interest. The

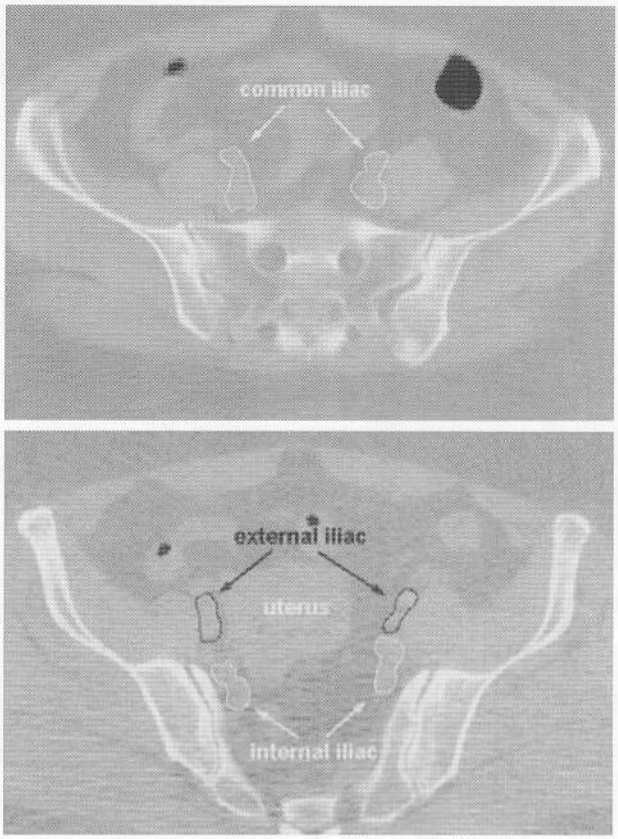

Fig. 1. CT images of iliac vessels. Top: common iliac vessels. Bottom: the external and internal iliac vessels.

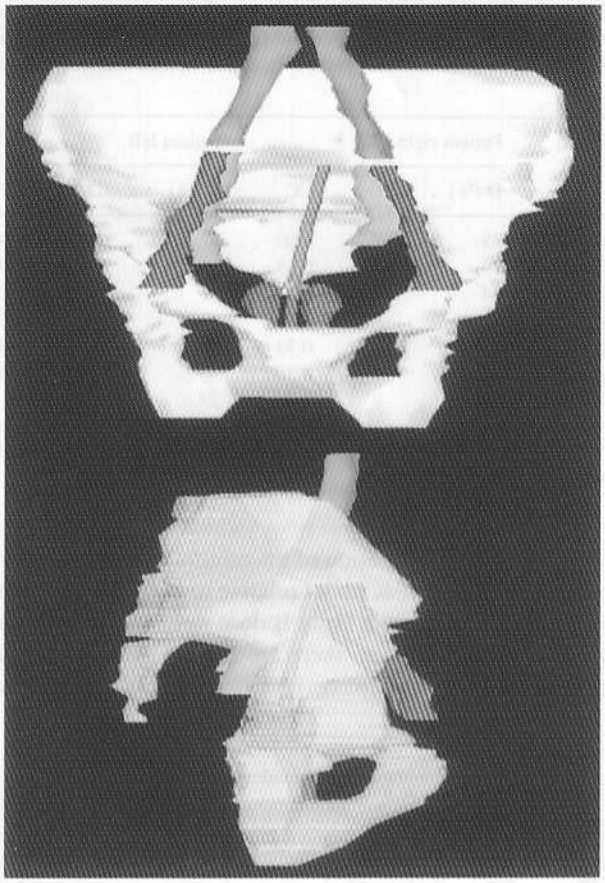

Fig. 2. 3D reconstruction of the tandem and ovoid applicator and iliac vessels (green, common; yellow, internal; and red, external). Top: AP view. Bottom: lateral view.

3D reconstruction was created and is shown in Fig. 2. A schematic of the general locations of the minimum and maximum doses referred to in this paper is given in Fig. 3. Depending on the particular implant geometry and anatomy for a given patient, Ilmin is located posteriorly at the most inferior aspect of the internal iliac chain. EIBmin is located at the most lateral positions at the top of the external iliac chain. The positions of points Ilmax and EImax varied along their respective chains, depending on individual patient implant geometry. They are generally centrally located (near the level of Point B) but this position can vary depending on tandem position and can be different for the same patient, patient right vs. patient left.

Table 1 summarizes the numerical average over the patient data for the dose rates EImax, EImin, EIBmin, Ilmax, Ilmin, and CImax and the corresponding Point B doses on both the left and the right. For reference, the average dose rate to Point A in cGy/h is listed. Regarding the maximum dose rates averaged over all implants, Point B on both the patient right and left is approximately the same as the corresponding maximum common iliac nodal dosage (CImax). Point B dose rates are, when averaged over the patient population, approximately 88 and 77% of the dose rates at EImax and Ilmax, respectively. For the minimum dose rates averaged over all implants, Point B is approximately double the minimum dosage to the internal iliac (Ilmin) nodal chain. It is triple the minimum dose to the external iliac chain. It is roughly 75% greater than the minimum external iliac nodal dosage at the bifurcation.

Table 1 showed the averages over all patients. The explicit, patient to patient dose variation is shown in Figs. 4 and

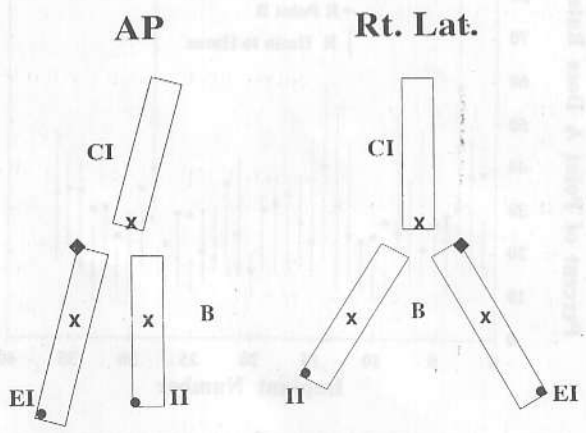

Fig. 3. Schematic AP and right lateral views of the patient right nodal chains. CI, EI, and II are the common, external and internal iliac chains, respectively. Circles (crosses) indicate minimum (maximum) doses to each nodal chain. A diamond shows the location of EIBmin.

Table 1
Averages over 36 implants of point doses (D), standard deviation (SD) and the correlation coefficient with Point B (CC) for various anatomical positions[a]

Position	Patient right			Patient left		
	D (%)	SD	CC	D (%)	SD	CC
IImax	38	17	0.60	37	17	0.64
IImin	14	4	0.63	16	5	0.64
EImax	34	17	0.88	32	11	0.56
EImin	9	3	0.44	9	3	0.30
EIBmin	17	6	0.79	16	5	0.68
CImax	29	19	0.76	30	15	0.65
Point B	29	8	1.0	29	7	1.0

[a] The doses are normalized to percent of Point A dose rate. Average Point A dose rate was 57.4 cGy/h.

5. Fig. 4 shows the variation of the minimum and maximum dose to the internal iliac nodes relative to Point B dose rates. In 50 out of 72 cases the Point B dose rate is between these two dose rates. However, there are 22 cases where Point B dose gives an overestimate of even the maximum dose

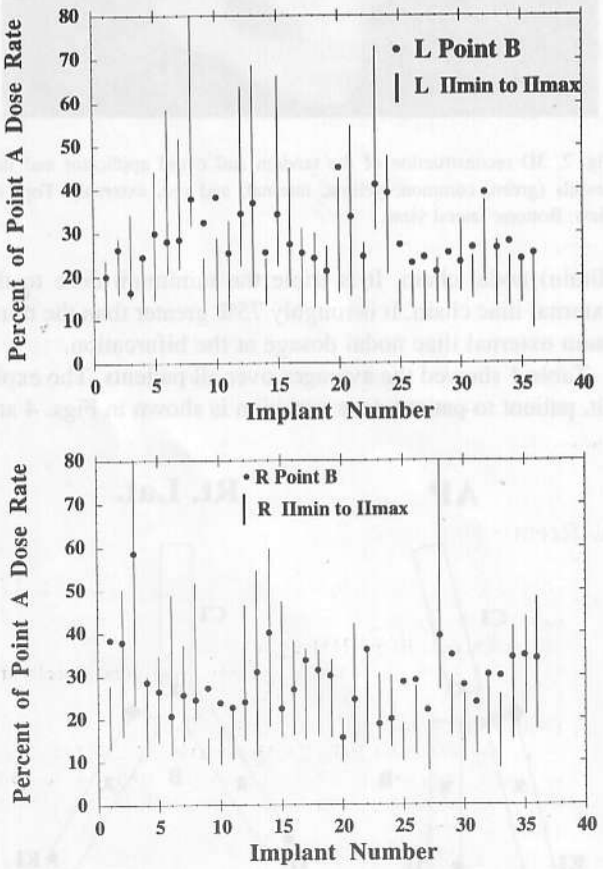

Fig. 4. Comparison of Point B dose rate with the minimum (Ilmin) and maximum (Ilmax) dose rates to the internal iliac nodes for the 36 implants. The circles designate Point B dose rate. The solid line represents the range of dose rates from Ilmin to Ilmax for that patient. Top half of the figure is patient left. Bottom half is patient right.

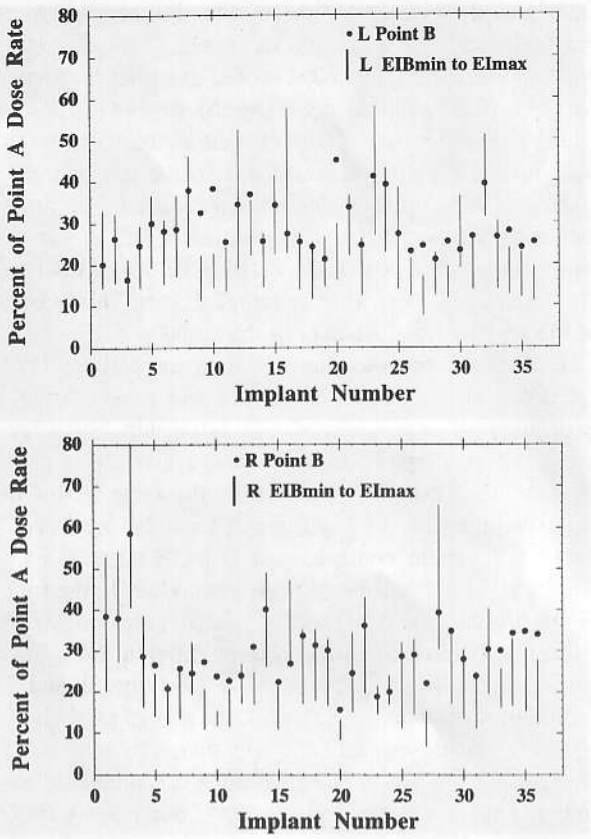

Fig. 5. Comparison of Point B dose rate with the minimum dose rate at the external to common iliac bifurcation (EIBmin) and the maximum dose rate to the external iliac nodes (EImax) for the 36 implants. The circles designate Point B dose rate. The solid line represents the range of dose rates from EIBmin to EImax for that patient. Top half of the figure is patient left. Bottom is patient right.

received. Fig. 5 shows the patient to patient variation of the minimum and maximum dose to the external iliac nodes relative to Point B dose rates. This is similar to what is seen in the case of the internal iliac lymph nodes. In 51 out of 72 measurements Point B lies between these two dose rates. In the remaining 21 implants, Point B overestimated the maximum dose received. When Point B was found to overestimate Ilmax, it also overestimated EImax in 63% of the cases. There are large patient to patient variations of Point B dose and maximum and minimum doses to the nodal chains, as shown in Figs. 4 and 5. This was especially true for the maximum dose rate estimations since their position resides in a region of larger dose gradient. Table 1 summarizes these results along with their large standard deviations. The correlation coefficient of each defined point with Point B is also given. Point B seems to correlate most strongly with EIBmin and CImax.

4. Discussion

This study presents the clinical results of a new method to

calculate the dose given to the lymph nodes with brachytherapy for cervical carcinoma. Using CT images, we calculated the dose rates to the external, internal, and common iliac nodal chains using the surfaces of the associated vessels as an estimate of their location. These nodal dose rates are approximations due to the use of the associated vessel anatomy to define their location. Nevertheless, assuming the nodal chains lay within 5 mm of the vessel walls, the error in dose is expected to be 3% of the Point A dose rate, or in absolute dose rate, 2 cGy/h. This is because of the smaller dose gradient at the nodal positions.

The results showed that for a given patient, Point B usually underestimated the EImax and overestimated the EIBmin dose rates. The same relationship holds for the internal iliac lymph node chain. Averaged over all patients, dose to Point B was approximately the same as to CImax. However, there is a large variance around the mean, and any individual patient could have a Point B and CImax dose rates significantly different from each other. In the superior to inferior dimension, CImax is located 3 mm from Ilmin or EIBmin. The dose to CImax is quite different from Ilmin or EIBmin because of the vessel size (see Figs. 1 and 3). It should be noted that CImax cannot be argued to be clinically significant as dose rates far lower than CImax exist in the common iliac chain even in the same CT slice as CImax is found. This is why we believe that if one point were to be chosen for clinical significance, EIBmin would be a reasonable choice as it is representative of the minimum dose at the bifurcation for all three chains.

In making the decision on how much to boost sidewall regions, it is reasonable to examine the minimum dose received to a lymph node chain. We found that Point B does not represent these minimum doses very well. From Figs. 4 and 5, Point B is closer to an average dose to the nodes. However, 33% of the time it overestimates the maximum dose. Nevertheless, Point B has a long history and is a very useful point for current clinical practice despite the fact that our results indicate that it cannot be counted on to represent any important nodal dose for a given patient. Its inaccuracies are tempered by the fact that the majority of dose to the region is administered via external beam treatments. As an example, a typical patient might have 45 Gy administered to the pelvic lymph nodes with external beam radiotherapy and an additional 12 Gy to Point B with brachytherapy. We have already stated that CImax dose cannot be a single crucial dose of importance. If we assume that an adequate dose to EIBmin is most important, one estimates (using Table 1 that EIBmin 57% of Point B):

Thus, because of the external beam component, the total dose to Point B is within 10% of the dose to EIBmin. Although, using Point B will overestimate EIBmin by 40% from the brachytherapy component, the total dose is within a few Gy. In general, 45–50 Gy is considered a sufficient dose to eradicate microscopic disease 90% of the time [3]. In the case of cervical cancer, higher doses (50–65 Gy) are commonly administered to Point B.

One can surmise that clinical practice has made up for the simplicity of Point B and this is why higher dose (measured at Point B) for microscopic disease is believed necessary in this region. If EIBmin point dose were considered for prescription, then the dose for microscopic control would be roughly in the 50–55 Gy range. If EIBmin were the basis for nodal dose quantification, one would have 48.7 Gy (using from Table 1 that EImin is 31% of Point B). The latter discussion is relevant to therapy prescription based on a single dose point.

This study failed to find a strong correlation between Point B dose and anatomically estimated nodal doses. It is not surprising that this is so. Point B, as seen from Fig. 3, functions as a regional estimate of the nodal doses without reference to individual implant or patient anatomy. If the situation were reversed, namely a long history of 3D anatomically defined multiple nodal doses for each patient were available instead of Point B dose experience, it is unlikely that anyone would choose Point B as providing a meaningful indicator of such data. Therefore, Point B should represent no more than what Tod and Meredith [7] stated it did, namely a measure of the 'proportional depth dose from A to B' and a rough estimate of the radiation dose to the nodal regions. In our day, CT-technology enables anatomically defined dose points to be used more easily. Substantial patient to patient variability and the large dose gradient (up to 300% brachytherapy component alone) across the nodal chains support continued research in this field. In radiation therapy there is a correlation between dose, disease control, and complications. 3D visualization and dosimetry may improve our ability to analyze patterns of failure and complications.

In summary, we have demonstrated 3D-CT dosimetry in tandem and ovoid treatment can be used to better understand the doses to the pelvic lymph node chains. We hope that continued accrual of this data will allow us to analyze the correlation of dose (calculated in this way) and treatment outcome.

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