Can point doses predict volumetric dose to rectum and bladder: a CT-based planning study in high dose rate intracavitary brachytherapy of cervical carcinoma?

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Objective: Point doses, as defined by the International Commission on Radiation Units and Measurements (ICRU), are classically used to evaluate doses to the rectum and bladder in high dose rate intracavitary brachytherapy (HDR-ICBT) in cervical cancer. Several studies have shown good correlation between the ICRU point doses and the volumetric doses to these organs. In the present study we attempted to evaluate whether this correlation could be used to predict the volumetric doses to these organs.

Methods: A total of 150 HDR-ICBT insertions performed between December 2006 and June 2008 were randomly divided into two groups. Group A ($n=50$) was used to derive the correlation between the point and volumetric doses using regression analysis. This was tested in Group B ($n=100$) insertions using studentised residuals and Bland–Altman plots.

Results: Significant correlations were obtained for all volumetric doses and ICRU point doses for rectum and bladder in Group A insertions. The strongest correlation was found for the dose to 2 cc volumes (D_{2cc}). The correlation coefficients for bladder and rectal D_{2cc} versus the respective ICRU point doses were 0.82 and 0.77, respectively ($p<0.001$). Statistical validation of equations generated in Group B showed mean studentised residual values of 0.001 and 0.000 for the bladder and rectum. However, Bland–Altman analysis showed that the error range for these equations for bladder and rectum were $\pm 64\%$ and $\pm 41\%$ of the point A dose, respectively, which makes these equations unreliable for clinical use.

Conclusion: Volumetric imaging is essential to obtain proper information about volumetric doses.

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Definitive radiotherapy of carcinoma of the cervix requires the integration of intracavitary brachytherapy (ICBT) in the treatment programme [1]. The rapid dose fall-off around the radioactive source allows the delivery of high radiation doses to the tumour with relative sparing of the rectum and bladder [2]. Although high dose rate (HDR) brachytherapy is considered to be radiobiologically inferior to low dose rate (LDR) treatments, owing to impaired sublethal damage repair during treatment, this disadvantage can be circumvented by the fractionation of dose and easier displacement of organs [3–5].

Classically, doses to the rectum and bladder are calculated and reported using the rectum and bladder reference points, as defined by the International Commission on Radiation Units and Measurements (ICRU) in Report No. 38 [6]. The simplicity and cost-effectiveness of radiograph-based planning has ensured its continued applicability for dose reporting in brachytherapy [7].

This is especially true in resource-constrained settings which bear the greatest burden of disease [8, 9].

Recent advances in volumetric imaging and applicator design have driven interest in three-dimensional planning and dose adaptation in gynaecological brachytherapy. The Gynecological (GYN) GEC ESTRO (Groupe Européen de Curiethérapie and the European Society for Therapeutic Radiology and Oncology) working group has made several recommendations dealing with image segmentation, dose prescription and plan analysis [10]; a special emphasis was placed on ensuring the use of a single and standardised terminology to facilitate reporting and comparison [11]. Implementation of these recommendations in clinical practice has resulted in increased local control compared with historical data and minimal treatment-related morbidity [12].

However, the high cost involved in the acquisition of specialised applicators and use of volumetric imaging modalities for each treatment session in HDR ICBT limits their use in resource-constrained settings [13]. In a systematic comparison of MRI and radiograph-based planning, Kirisits et al [14] have shown that there is a good correlation between point doses and minimum dose to the most exposed 2 cc volume (D_{2cc}) for both bladder and rectum. The present study was designed based on the

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hypothesis that this correlation might be used to derive a clinically useful predictive relationship between point and volumetric doses and to give a quantitative estimate of the error in such an equation. Derivation of such a relationship could ease the transition from two-dimensional to three-dimensional planning in gynaecological brachytherapy and allow meaningful use of the extensive data available from classic radiograph-based planning in a relevant fashion in the image-based era.

Methods and materials

Selection criteria and patient population

Since December 2006, CT-based planning for brachytherapy was used in place of radiograph-based planning for gynaecological brachytherapy in our department. From December 2006 to June 2008, 80 patients had undergone 2 sessions of HDR ICBT each in our institute (total = 160 insertions) using microSelectron applicators (Nucletron BV, Veenendaal, the Netherlands). In these 160 insertions, CT-based planning was performed in 150, while radiograph-based planning was used in the remaining 10 (owing to the unavailability of CT simulator as a result of technical reasons).

The whole population of 150 insertions was randomly divided into two groups (Group A and B) by simple random sampling. Group A (50 ICBT insertions) was used for evaluating the correlation between the point and volumetric doses. The point doses were regressed against the volumetric doses in order to generate the formula for predicting the volumetric organ doses from the respective point doses.

The formula obtained was used in Group B (100 ICBT insertions) for calculation of a predicted volumetric dose from the point doses. The predicted and actual doses were then used for validation of the formula generated.

Written informed consent about the ICBT and CT scan was taken prior to conducting the individual procedures. Special ethical clearance was not required owing to the retrospective nature of this analysis.

ICBT technique

All patients underwent two sessions of ICBT, 1 week apart, after whole pelvic external beam radiotherapy (EBRT) to a dose of 46 Gy in 23 fractions. No midline shielding was used. ICBT was performed 1–2 weeks after completion of EBRT. Standard metallic HDR micro-Selectron after-loading applicators (Nucletron BV) were used. All applications were performed under general anaesthetic and involved placement of an intrauterine tandem and vaginal ovoids. A radio-opaque marker was placed against the posterior vaginal wall. Vaginal packing with dry gauze was carried out to fix the applicator in position and to displace the bladder and rectum away from the vaginal applicators. A stitch was placed on the vulva to secure the system in place.

Image acquisition

CT simulation was performed using helical CT (Lightspeed VXR 16, GE Medical Systems, Waukesha,

WI) without any dummies inside the applicator. Prior to the scan, 7 cm³ of radio-opaque dye (1:4 dilution) was instilled in the balloon of a Foley's catheter, which was then pulled snugly against the trigone of bladder. A specialised scan protocol utilising differential slice thickness was used to ensure the best visualisation of the applicator while minimising the number of CT slices used. The slice thickness was 2.5 mm from the tip of the tandem to the superior surface of the ovoids and 0.65 mm from the superior surface of the ovoids to the inferior surface. The scanned volume extended from 2 cm above the tip of the applicator to 5 cm below the inferior surface of the ovoids to ensure the entire bladder was included in the scanned volume. During image acquisition and treatment the bladder was continuously drained through the indwelling catheter.

Contouring

The rectum and bladder were contoured as solid organs and wall delineation was not carried out [10]. The rectal contours extended 2 cm superior and inferior to the most cephalad and caudad brachytherapy sources, respectively [15]. Image segmentation was performed on the Advantage Sim Workstation 4.3 (GE Medical Systems). After contouring, both the image and the structure sets were transferred to the PLATO Sunrise brachytherapy planning workstation for planning and calculation (Nucletron BV).

Planning and quality assurance

Applicator reconstruction was performed in the PLATO Sunrise Workstation (Nucletron, Veenendaal, the Netherlands) using the multiplanar reconstruction (MPR) view. In order to delineate a particular channel, the axis of the image was manipulated so that it passed through the desired channel. This provided a display of a reformatted CT image in the desired plane (Figure 1). In this view, the tip and channel could be easily demarcated and reconstructed following the curvature of the catheters. The dwell positions in the tandem and the ovoids included an offset of 4 mm from the tip.

Quality assurance of the reconstruction process had been performed prior to initiation of the protocol. The procedure included comparison of the channel lengths and curvatures measured in autoradiographs against those constructed in the MPR view in the planning system. In addition, the accuracy of the offset for the first dwell position in the uterine tandem and ovoids was checked against the autoradiographs.

Dose calculation and planning

The ICRU bladder point and rectal points were identified on the CT scan based on the standard definition. The dwell positions for a typical application of 6 cm uterine tandem and 2 cm ovoids were 3, 6, 9, 12, 15, 18, 21 and 24 for the tandem and 3, 4, 5 and 6 for the ovoid, respectively. Point A was defined as per the classical

Figure 1. Multiplanar reconstruction (MPR) view for applicator reconstruction. (a) The reconstructed channel in the three-axis view. Note the clear definition of the channel tip with minimum artefact. (b) The method for quality assurance of the reconstruction method. The distance of the first dwell position of 4 mm matches with the measurements obtained in the autoradiographs.

definition. A dose of 900cGy per fraction was prescribed at Point A. No optimisation was done. Doses at ICRU bladder and rectal point were noted. Minimum doses to the most exposed 0.1, 1, 2 and 5 cc volume of the rectum and bladder ($D_{0.1cc}$, D_{1cc} , D_{2cc} and D_{5cc}) were obtained from the respective dose–volume histogram tables. The biologically equivalent doses (BED) for each fraction were calculated using the formula given by Dale [16].

BED for each fraction = $D(1 + D/(\alpha/\beta))$, where D is the dose to a specific subvolume of the organ for that specific fraction. The α/β ratio was taken as three to represent late-reacting tissue for both rectum and bladder.

Study design

The dose distribution in ICBT follows the inverse square law, which implies that a good correlation can be obtained between doses at two disparate points if they have a near-fixed relationship to each other. Thus, evaluating the correlation coefficient between two dosimetric parameters is not alone sufficient. Our study therefore proceeded in three steps. In the first step we ascertained the strength of the correlation between the point doses and volumetric doses, which was then used to derive a predictive equation. The second step assessed whether the doses predicted by these equations were statistically valid in an independent population. The third step was to determine the extent of inaccuracy in the predictions made by these equations so that the clinical usefulness of the predictive equation could be gauged.

Statistical analysis

Statistical analysis was performed using SPSS version 16.0 software (SPSS, Chicago, IL). The Mann–Whitney test was used for comparing the distribution of non-parametric variables like tandem length and ovoid type between Groups A and B. Parametric variables like doses to the bladder and rectum were compared using the unpaired t -test.

The doses in Group A were used to assess if the ICRU point doses could predict the corresponding organ doses to various subvolumes. Descriptive statistics, including the mean and 95% confidence intervals (95% CI) of the mean, were calculated. Bivariate correlations were performed using the Pearson product moment correlation method with the Bonferroni correction. Linear regression analysis using the least squares method was used for obtaining the equation for the best fit line in the scatter plots. The Kolmogorov–Smirnov test was used to confirm that the residuals were normally distributed. The effect size for the correlation and regression analysis have been reported as given by Cohen [17], where a strong correlation is stated to exist when the correlation coefficient is equal to or more than 0.6.

The equations generated were validated in Group B using studentised residuals [18]. The residual is the difference between the observed and the predicted doses (D_{O-P}). The studentised residual is the residual divided by the standard error of the residual ($D_{O-P}/SE(D_{O-P})$). The model was considered mathematically valid if in the plot of the studentised residual versus the predicted doses 95% of the observations lay between 0 and ± 2 standard deviations (SD) around the mean [19].

As the use of studentised residuals does not give an indication of the magnitude of error in the predictive equation, Bland–Altman plots were used to ensure that the equations were useful for clinical use [20]. To this end, the D_{O-P} was plotted against the mean of the observed and predicted dose (D_{mean}). As per the methodology given by Bland and Altman [20], the equation was considered to be useful if the range between the mean of $D_{O-P} \pm 2$ SD was clinically acceptable. In addition, the differences must not have varied systematically over the range of measurement (*i.e.* the scatter plot generated must not have shown an increase towards one side along the x axis). We also predefined the range of mean $D_{O-P} \pm 2$ SD to be 0.9 Gy (10% of the prescribed Point A dose) in order to consider the equation to be clinically useful.

Results

Comparison between groups

Patients in the two groups were compared with respect to the applicator types and organ doses to exclude heterogeneity between the groups. There was no significant difference in the tandem length or ovoid type used between the two groups. The mean $D_{2\text{cc}}$ for the bladder was 936 cGy (104% of Point A dose; 95% CI 865–1006 cGy) and 948 cGy (105.3% of Point A dose; 95% CI 909–988 cGy) in Groups A and B, respectively ($p=0.74$). The corresponding mean $D_{2\text{cc}}$ for the rectum was 529 cGy (58.7% of Point A dose; 95% CI 481–578 cGy) and 562 cGy (62.4% of Point A dose; 95% CI 533–592 cGy) in the two groups ($p=0.22$). No significant differences were seen in the ICRU point doses to these organs in between the two groups.

Generation of the equation (Group A)

There was a strong correlation between the ICRU bladder point doses and all bladder subvolume doses

(data not shown). The best correlation was seen between the ICRU point dose and $D_{2\text{cc}}$ bladder (correlation coefficient = 0.82, $p < 0.001$). The mean ICRU bladder point dose was 796 cGy (88.4% of Point A dose; 95% CI 707–885). A linear regression plot of the ICRU bladder dose against the $D_{2\text{cc}}$ bladder is shown in Figure 2a. The coefficient of determination for this equation was 0.67, which meant 67% of the variability in $D_{2\text{cc}}$ could be accounted for by this equation.

As in the case of the bladder, there was a high degree of correlation between the ICRU rectal point dose and volumetric dose to all rectal subvolumes. The best correlation was obtained between the ICRU rectal point dose and the $D_{2\text{cc}}$ rectum ($r=0.77$, $p < 0.001$). The mean ICRU rectal point dose was 516 cGy (57.3% of Point A dose; 95% CI 477–554 cGy). Figure 2b shows the scatter plot of the ICRU rectal point dose versus the $D_{2\text{cc}}$ rectum. The coefficient of determination for this equation was 0.59, which meant that the equation could explain about 59% of the variability in the data set.

The corresponding equations generated from the linear regression analysis for the bladder and rectum are given below:

$$D_{2\text{cc}} \text{ BLADDER} = 0.655 (\text{ICRU bladder point dose}) + 0.461 \quad (1)$$

$$D_{2\text{cc}} \text{ RECTUM} = 0.960 (\text{ICRU rectal point dose}) + 0.038 \quad (2)$$

All the doses in the equations are with doses normalised to Point A.

Mathematical validation of the equations (Group B)

Using Equations (1) and (2), predicted doses in Group B patients were then regressed against the actual doses and studentised residuals calculated. The mean value of

Figure 2. (a) Scatter plot of normalised bladder $D_{2\text{cc}}$ versus the ICRU bladder point dose. (b) Scatter plot of normalised rectal $D_{2\text{cc}}$ versus ICRU rectal point dose. All doses are normalised with respect to the Point A dose.

Figure 3. Plots of studentised residuals against predicted D_{2cc} for (a) bladder and (b) rectum. Note that 95% of the observed values lie within the mean ± 2 SD.

the studentised residual for the bladder was 0.001 (SD ± 1.005). The mean value of the studentised residual for the rectum was 0.000 (SD ± 1.010). Of the total observations, 95% were between mean ± 2 SD in the plot of the studentised residual versus the predicted doses for both bladder and rectum (Figure 3). Both equations could be considered to be mathematically valid.

Validation for clinical use (Group B)

Bland–Altman plots were generated for the normalised doses for the bladder and rectum (Figures 4 and 5). As seen in the plots, the range between the mean of $D_{O-P} \pm 2$ SD was 0.64 for the bladder (64% of Point A dose). The range for the rectum was 0.41 (41% of Point A dose).

Discussion

The concept of ICRU points for the rectum and bladder was initially proposed in an effort to standardise dose reporting in ICBT [6]. Owing to the sharp dose gradients seen in ICBT, an accurate and reproducible method of dose reporting is essential. Although the ICRU points have served this purpose, their utility in predicting significant late toxicity has been debated. Chen et al [21, 22] have shown in two studies that cumulative rectal point doses exceeding 65 Gy are associated with increased rectal toxicity. However, both Chen et al [23] and Ferrigno et al [24] have shown that the ICRU rectal point doses fail to correlate with the toxicity. Cheng et al [23] also showed that the dose to proximal rectal point correlated better with the rectal toxicities, as compared with the ICRU point dose. The correlation between bladder point doses and late radiation-induced cystitis is even more tenuous [24].

Despite this readily understood weakness of ICRU points in predicting actual toxicity, their use has been understandably widespread. Even in developed countries the majority of dose reporting is done on the basis of

radiograph-based planning and ICRU points. In a recent survey, Viswanathan et al [25] reported that almost 43% of oncologists in the USA use radiograph-based planning during gynaecological brachytherapy and 52% use the ICRU point doses exclusively for evaluation of doses to the rectum and bladder. Pearce et al [7] have reported in a Canadian survey that 89% of the responding radiation oncologists use orthogonal radiograph-based planning in ICBT. Similar findings have been reporting by Guedea

Figure 4. Bland–Altman plot for validation of the equation predicting bladder D_{2cc} . The solid line represents the mean of the difference between the observed and predicted dose (D_{O-P}). The dotted lines represent 2 SD around the mean, the interval between which represents the magnitude by which the actual dose can vary from the predicted dose in 95% of the observations. The dashed lines on either side of the dotted lines show the precision of the limits of agreement or the 95% confidence interval of the upper and lower limits of the above magnitude. This represents the range in which the upper and lower limits of agreement will lie if the measurement is repeated in a different sample. All doses are normalised to Point A.

Figure 5. Bland-Altman plot for validation of the equation predicting rectal D_{2cc} . The solid line represents the mean of the difference between the observed and predicted dose (D_{O-P}). The dotted lines represent 2 SD around the mean, the interval between which represents the magnitude by which the actual dose can vary from the predicted dose in 95% of the observations. The dashed lines on either side of the dotted lines show the precision of the limits of agreement or the 95% confidence interval of the upper and lower limits of the above magnitude. This represents the range in which the upper and lower limits of agreement will lie if the measurement is repeated in a different sample. All doses are normalised to Point A.

et al [26], with less than 10% of respondents using MRI and less than 40% having access to CT for brachytherapy dosimetry in Europe. It is therefore easy to see that radiograph-based planning and dose evaluation based on ICRU points could be commonplace in the foreseeable future, especially in resource-poor settings.

The use of volumetric imaging has several advantages in gynaecological brachytherapy, as greater information on the actual dose and the spatial dose distributions in the organs at risk can be obtained [11]. In addition, unlike the ICRU points the dose to the specified organ is calculated instead of a surrogate (e.g. dose to the posterior part of the balloon of a Foley's catheter) [27]. MRI-based individualised planning has been used to escalate the dose during brachytherapy without increasing the late morbidity [12]. The Vienna group has also shown that the D_{2cc} rectum correlates well with rectal toxicity, as measured on the Vienna rectoscopy score (VRS) and late effects in normal tissue subjective, objective, management and analytic (LENT SOMA) scales [28]. Similar studies with respect to the correlation of bladder dose and toxicity are lacking; this paucity could result from the short follow-up available in most

studies reported to date, together with the higher tolerance of the bladder to radiation [28].

Several studies have described the differences between the ICRU point doses and volumetric doses for the rectum and bladder (Table 1) [29–31]. As shown, the actual difference in the dose between the ICRU rectal point and the D_{2cc} ranges from 21 to 39 cGy, whereas the difference for the bladder is more variable ranging from 83 to 680 cGy. Wachter-Gerstner et al [27] showed that the ratio of the ICRU point doses to the D_{2cc} was 0.9 for the bladder and 1.5 for the rectum; however, reporting the difference in dose carries the fallacy that it depends on the actual dose prescribed, which can be variable.

The correlation between the point and volumetric doses for the bladder and rectum has been reported in several studies (Table 2) [32–34]. The majority of these studies have shown a close relationship between the ICRU rectal point dose and D_{2cc} . In addition, Wang et al [34] have also shown that the ICRU bladder point dose is a fairly good predictor of the D_{2cc} . In another recent study by Kirisits et al [14], both bladder and rectal point doses were shown to have good correlation with D_{2cc} .

In the present study, a good correlation was observed between ICRU point doses and volumetric doses for various subvolumes for both rectum and bladder. The best correlation was observed for D_{2cc} for both bladder and rectum. On average, the D_{2cc} exceeds that of ICRU bladder reference doses by 27.11%, whereas the ICRU rectal point underestimated the D_{2cc} by only 3.3%. Further analysis including regression and validation were performed using the D_{2cc} only, as ICRU point doses correlated best with the D_{2cc} to organs. In addition, as highlighted earlier, this volume is clinically relevant as D_{2cc} is a good predictor of toxicity.

Studies to date have reported somewhat conflicting results in terms of the correlation between the point and volumetric doses for the bladder (Tables 1 and 2). This disparity probably stems from the variation in brachytherapy practice worldwide, especially in the use of general anaesthesia and bladder filling. Wachter-Gerstner et al [27] have reported that bladder doses show better correlation with the point doses if the volume is kept below 130 cm³. In the study by Pelloski [29], which showed greater difference between the doses, dilute hypaque was instilled in the urinary bladder, which might have augmented the bladder filling. The poorer correlation obtained for the rectal doses by the single study of Yaparpalvi et al [32] could be a reflection of the combined intracavitary interstitial implant technique used in the study. The good correlation for both rectum and bladder observed in the present study might result from the use of a standardised application methodology, which involves the use of general anaesthesia to achieve maximum relaxation, prior rectal

Table 1. Studies reporting the difference in dose^a between ICRU reference points and D_{2cc} for bladder and rectum

Author	n	Mean difference bladder (cGy)	Mean difference rectum (cGy)
Pelloski et al [29]	93	680	21
Addeo et al [30]	30	176	32
Kim et al [31]	22	83	39

^aThe mean difference in the dose is shown. D_{2cc} , the dose to 2 cc volumes; ICRU, point doses as defined by the International Commission on Radiation Units and Measurements.

Table 2. Compilation of results of various studies showing the relationship between the ICRU point doses and D_{2cc}

Author	n	Applicator type used	Correlation coefficient bladder ^a	Correlation coefficient rectum ^a
Yarpalvi et al [32]	30	Combined interstitial and intracavitary	0.23	0.91 ^b
Van den Bergh et al [33]	13	TO	NA	0.5 ^b
Wang et al [34]	50	TR	0.67 ^b	0.25
Present study	50	TO	0.82 ^b	0.77 ^b

^aCorrelation coefficients are Pearson's correlation coefficients between the ICRU point dose and D_{2cc} for the respective organ.

^bSignificant correlation. D_{2cc} , the dose minimum to 2 cc volumes; ICRU point doses, as defined by the International Commission on Radiation Units and Measurements; TO, tandem ovoid type applicators; TR, tandem ring type applicators.

emptying with enemas and continuous bladder drainage using indwelling catheterisation to minimise variation in organ volumes.

The use of correlation coefficients is not an ideal approach to evaluate if two methods of measurement agree [20]. Correlation merely measures the strength of a relationship, while the agreement between the two methods means they give the same result.

We therefore attempted to test whether the formulae generated in Group A patients could be used in a larger series of patients treated in the same fashion (Group B). The equations were first statistically validated and Bland–Altman plots were utilised to quantitatively measure the magnitude of error in the predicted doses.

Bland and Altman proposed their method for measuring the agreement between two tests designed to measure the same variable [20]. In the present study, the equations generated from the linear regression analysis in Group A patients were taken as the “new measurement method”, whereas the CT-calculated doses were taken as the “established measurement method”.

We pre-defined a range of 10% of the prescribed dose as an acceptable limit of agreement between the two methods. In other words, the average of the difference between the observed and predicted doses (mean of $D_{O-P} \pm 2$ SD) was to be within 10% of the prescribed dose to Point A for the equation to be considered statistically valid. The reason for choosing this limit is best illustrated by an example: assuming a prescribed dose of 9 Gy and a predicted rectal D_{2cc} of 6 Gy, an uncertainty of 10% of the prescribed dose in the estimate means that the actual rectal dose can vary from 5.1 to 6.9 Gy (6 ± 0.9 Gy). This is equivalent to a BED range of 13.77 Gy _{$\alpha/\beta=3$} to 22.77 Gy _{$\alpha/\beta=3$} , an uncertainty of $\pm 26\%$ over the predicted BED of 18 Gy _{$\alpha/\beta=3$} .

As can be seen from Figures 4 and 5, the range between the limits of agreement is far wider. In the case of the bladder, the range for the limits of agreement between the two methods is 0.64 (or 64%) of the prescribed dose to Point A. In terms of actual dose this translates into an uncertainty of 576 cGy in our series. In the case of the rectum, the range was 0.41 (41% of prescribed dose to Point A), which translates into an uncertainty of 369 cGy. By our own pre-defined criteria, neither equation can be considered useful for clinical use owing to the wide range of uncertainty in the measurement.

At the inception of this study the authors were well aware that the nature of the regression equation would change with the size of the sample. To minimise any errors in the estimation owing to a small sample size, we included the entire population of HDR intracavitary insertions undergoing CT-based planning in our institute

in the period specified. The inability of the point-based doses to accurately predict the volumetric doses in such a large data set will probably be applicable for other patient populations. To the authors' knowledge, the present study is the first to systematically and quantitatively evaluate the errors in such predictive relationships.

The reasons for this wide variation are manifold. ICRU point doses are surrogates of the applicator or the Foley's catheter balloon defined on orthogonal radiographs. In the case of the rectum, the ICRU rectal point might lie outside the rectum in several cases. The bladder doses are influenced by the position of the catheter, variable wrapping of the organ around the uterus and its filling status. The high-dose gradients seen in brachytherapy mean that even small errors in contouring or any anatomical variation in the organ would shift the volume receiving the high dose away from the location of the ICRU points. Therefore, volumetric doses cannot be predicted accurately by point-based doses.

Conclusion

In this study of CT-based dosimetry of brachytherapy applications in carcinoma of the cervix, all point doses demonstrated a uniform strong positive correlation with the volumetric dose parameters. The best correlation was seen between the point doses and the D_{2cc} for both rectum and bladder. The predictive relations between the ICRU point dose and D_{2cc} for both bladder and rectum were also statistically validated in a larger data set. Nevertheless, equations obtained cannot be considered useful for clinical use owing to wide error margins in the estimates. Thus, information about volumetric doses is best obtained from three-dimensional imaging modalities and ICRU point doses cannot be used to predict the dose to organ volumes accurately despite a good correlation.

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