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Original Article

The Implementation of the Gynaecological Groupe Européen de Curiethérapie – European Society for Therapeutic Radiology and Oncology Radiobiology Considerations in the Conversion of Low Dose Rate to Pulsed Dose Rate Treatment Schedules for Gynaecological Brachytherapy

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Abstract

Aims: This paper details the considerations and calculations made by this centre for the implementation of the biologically equivalent dose in 2 Gy fractions (EQD_2) radiobiology calculations recommended by the Gynaecological Groupe Européen de Curiethérapie – European Society for Therapeutic Radiology and Oncology, in converting our cervix, body of uterus and vaginal vault low dose rate (LDR) treatment prescription schedules for caesium-137 to equivalent pulsed dose rate (PDR) protocols using iridium-192.

Materials and methods: The assumptions made in order to calculate the EQD_2 for both the LDR and the corresponding PDR schedules are detailed. The source geometries and prescription points are discussed for all standard treatment schedules. The prescription point for vaginal vault treatments has been altered to a 5 mm depth rather than the applicator surface, and the prescribed dose for all applicator sizes has been normalised at this depth.

Results: The calculated PDR schedules are presented, with corresponding target and organ at risk values given for LDR and PDR versions of standard treatment schedules. A standard 32.5 Gy point A cervix prescription used in Manchester with LDR has been converted to 2 × 19 Gy for PDR.

Conclusions: PDR schedules have been calculated to correspond with our established LDR treatments in terms of EQD_2 dose to the target. There is a theoretical improvement in the therapeutic ratio due to a reduction in the calculated EQD_2 to organs at risk.

Key words: Brachytherapy; gynaecological; LDR; PDR; radiobiology

Introduction

Since 1932, the evolution of dose distributions and prescriptions for cervix brachytherapy treatments at the Christie Hospital has been well documented for pre-loaded radium sources [1,2] and converted in 1978 for after-loaded low dose rate (LDR) caesium applications [3–5]. The LDR Selectron after-loading device is no longer manufactured or supported [6], hence the necessity to move forward to an alternative brachytherapy after-loading treatment unit. A clinical decision was made locally in favour of pulsed dose rate (PDR) rather than high dose rate (HDR) brachytherapy. The theoretical radiobiological advantage of PDR over HDR was the major deciding factor [7,8], in addition to a potential logistical problem of increasing the annual workload of gynaecological brachytherapy treatments of ~180 annually by a factor of three or four if HDR brachytherapy was considered.

European guidelines for three-dimensional treatment planning in cervix cancer brachytherapy have been published by the European brachytherapy society, Groupe Européen de Curiethérapie – European Society for Therapeutic Radiology and Oncology (GEC-ESTRO) [9,10]. These guidelines cover the planning, prescribing and reporting of brachytherapy for cervix treatments. The radiobiological formulae recommended for calculating the biologically equivalent dose in 2 Gy fractions (EQD_2) is defined for LDR, PDR and HDR in the appendix to the (GYN) GEC-ESTRO II guidelines [10]. It was necessary for us to determine the equivalent PDR prescriptions for the full range of our LDR prescriptions, for cervix, body of uterus and vaginal vault treatments.

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Materials and Methods

Radiobiological Calculations

The initial clinical decision was made to deliver 1 Gy per pulse in hourly intervals, for all gynaecological PDR treatments. This is in line with the range recommended by (GYN) GEC-ESTRO [10] and the Royal College of Radiologists [8].

The dose and fractionation for the external beam component of the pelvic treatments remains unchanged (40–45 Gy in 20 fractions over 4 weeks). Therefore, only the EQD_2 for the LDR/PDR brachytherapy was compared.

The EQD_2 was calculated from the biologically effective dose, which according to the familiar linear quadratic model is given by:

$$BED = Nd\left(1 + g\frac{d}{\alpha/\beta}\right)$$

where:

- N is the number of treatment fractions or pulses
- d is the dose per fraction or pulse. It was assumed that the organs at risk (OAR) received 70% of the prescription dose, as per the Royal College of Radiologists guidelines [8], and also the American Brachytherapy Society recommendations [11]. It should be noted that this 70% value is not indicative of the maximum dose received by each OAR, such as with a $D2$ cc value, but rather is used as a representative figure, with reference to the literature [8,11].
- The α/β ratio was taken to be 10 Gy for the target volumes and 3 Gy for the OAR, including the bladder, rectum, sigmoid and small bowel, as recommended by (GYN) GEC-ESTRO [10].
- g is the incomplete repair function whose form is dependent upon the brachytherapy treatment modality; formulae for g(LDR) and g(PDR) are given in full in the (GYN) GEC-ESTRO II appendix [10]. Both are dependent upon $T_{½}$, the mono-exponential repair half-time; a value of 1.5 h is recommended by (GYN) GEC-ESTRO [10].

As the values of the repair half-time are less well established than for the α/β ratio [10], we calculated the effect of varying the repair half-time between 0.5 and 2.5 h for one of our LDR regimens and our chosen PDR replacement regimen. Over this range, with the exception of very short half-times of the order of 0.5 h, the OAR dose is lower for PDR and the tumour dose will be no more than 5% lower for PDR compared with LDR.

For LDR, the incomplete repair function, g, is dependent upon the overall treatment time. For PDR, g has a more complex form, and includes the following additional parameters:

- t is the time for each pulse, which varies depending upon the current reference air kerma rate (RAKR) and the geometrical arrangement of dwell positions and prescription point(s). A value of 15 min was assumed, as per the Royal College of Radiologists guidelines [8]. Variation in this factor had a minimal effect on the calculation; the EQD_2 varies by no more than 0.5% between pulse times of 0.01 and 1 h.
- x is the time between pulses without irradiation; this is equal to the pulse interval, which we set to 1 h, minus t, the time for each pulse.
- N is the total number of pulses. It was decided that we would derive the whole number of pulses giving the EQD_2 nearest to that delivered by the corresponding LDR treatment schedule. By using whole numbers of pulses only, the time for each pulse would be the same, enabling a simpler checking process and minimising any potential confusion in the pulsed treatment schedule. In addition, for the same reason, where multiple fractions were necessary, we would use an equal number of pulses for each fraction.

Prescription Points and Source Geometry

The LDR gynaecological treatments at the Christie Hospital fall into three prescription categories: cervix prescriptions to Manchester system point A, body of uterus prescriptions to the nominal body dose (NBD) points and vaginal vault treatments to the maximum vaginal mucosal dose point (on the applicator surface).

Cervix

These treatments aim to treat the cervix using a combination of uterine sources (within a central tube) and vaginal loading using either a pair of ovoids or within vaginal applicator units placed onto the central tube below the flange.

The standard historical treatment [2] upon which the LDR treatment time calculations are based is a central tube with a pair of ovoids.

Using the Manchester system, when transverse ovoids could not be accommodated within the patient at the vaginal vault, ovoids in tandem were used with the standard treatment time, but due to a lower dose rate to point A, a lower dose was received. Tod and Meredith [12] state:

> It is not considered advisable to increase the treatment time to eliminate this reduction because of the greater length of the rectum and vagina which are exposed to the already considerable doses of radiation.

The ovoids in the tandem source arrangement have been mimicked with an LDR single train of sources in the vagina, using an eight-pellet loading pattern. More commonly, a shorter, five-pellet loading pattern was used clinically within a vaginal cylinder, with a slightly increased treatment time to give the same dose to point A as achieved for the eight-pellet loading pattern.

The resultant dose to point A for these treatments is an average of 8.3% lower (within a range of 6.2–10.6% over all geometries) than the prescription dose for the standard central tube and transverse ovoid pellet arrangement. In order to convert our LDR regimens to PDR, the 8.3%